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A. R. CHI

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Network Engineering Division

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ABSTRACT

With the advent of space science and applications the requirements for precise and accurate time and time interval have approached to the order of microseconds and below. To meet these needs users must examine the various techniques to maintain the time scale and assess their long-term performance.

LORAN-C navigation system has been widely used in the last few years as a precise time reference signal for international comparison of the primary clocks in the northern hemisphere. This paper presents the long term performance of the eight LORAN-C chains in terms of the Coordinated Universal Time (UTC) of the U.S. Naval Observatory (USNO) and the use of the LORAN-C navigation system to maintain the user's clock to a UTC scale.

The atomic time (AT) scale and the UTC of several national laboratories and observatories relative to the international atomic time (TAI) are presented. In addition, typical performance of several NASA tracking station clocks, relative to the USNO master clock, is also presented.

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ON TIME SCALES AND TIME SYNCHRONIZATION USING LORAN-C AS A TIME REFERENCE SIGNAL

INTRODUCTION

National time keeping and maintenance agencies for each country have primary responsibilities in the maintenance and dissemination of accurate time to the users. These primary clocks which provide the accurate time are maintained on a long term basis and are traceable to the origin of an epoch. The time signal¹ are disseminated through radio frequency emissions or other techniques to users, including other national time keeping agencies. The international comparison of time signals among the national time keeping agencies formulate the data base for the adoption of uniform time scales such as the Coordinated Universal Time (UTC) and the International Atomic Time (TAI). It is the time as a scale rather than the time as an epoch that is in increasing demand by modern users.

With the advent of space science and applications in the last decade the requirements for precise and accurate time and time interval have approached the capabilities of national time keeping and maintenance agencies. To satisfy the sophisticated users, the national time keeping agencies issue time corrections periodically in the form of bulletins or announcements. These corrections are given relative to a primary time standard or master clock. For example, the Bureau International de l'Heure (BIH) issues a monthly circular, circular D, which gives the time comparison between the various national time standards relative to UTC and TAI. The use of these bulletins, announcements, and circulars and the long term stability of the primary time standards relative to the international adopted time scales is presented in this report. Users who need precise and accurate time and time interval on the order of microseconds or better undoubtedly recognize the need to use these corrections. The proper interpretation of the user's requirements in terms of time or time interval, the difference between accuracy and precision of measurement, and the accuracy of maintaining a clock relative to a time scale is generally the responsibility of the users who must communicate effectively to those experts who generate and maintain the time standards and/or who provide the techniques for clock synchronization.

CLOCK COMPARISON TECHNIQUE AND DATA

Clock comparison techniques are numerous and vary in accuracy and precision. In general, radio frequency transmissions in VLF, LF, and HF bands have been used as the work-horse and provided continuous, reliable and real-time

time transfer references for clock comparisons. Portable clocks, satellites (both natural and artificial), and coherent radiations from quasars are in increasing use to meet specific needs. As the accuracy in timing requirements is increased, not only must the accuracy of transmission and the precision of measurement be increased, but also the stability of the oscillators (fly wheel) which generate the time must be increased.

The most often used time transfer reference signal for clock comparison among primary clocks in national laboratories is the 100 kHz transmissions of the LORAN-C navigational system. At present, LORAN-C consists of eight chains which provide adequate coverage for the northern hemisphere. The resolution of time comparison of an identified cycle of the received signal is about 1/100th of a cycle or 0.1 microseconds. The long term stability of the propagation delay, even for groundwave, is probably not much better than ± 0.5 microsecond. The long term stability of the time transmission of a LORAN-C chain at present is about one order of magnitude lower.

The data collected by each national laboratory or observatory is published and is available to the users. For example, in the United States the Naval Observatory issues to general users a series of time bulletins and announcements on a weekly basis, and sends corrections by telegrams on a daily basis to special users. The National Bureau of Standards issues a special publication, NBS Special Publication 236, on a monthly basis. In other countries, for example in the United Kingdom, the Royal Greenwich Observatory publishes a monthly Time Service Circular. Also, the National Research Council of Canada publishes their LORAN-C measurements in letter form once every ten days and Time and Frequency Bulletins monthly. The Institute Electrotecnico Nazionale of Italy publishes a monthly circular and the Bureau International de l'Heure publishes monthly circulars and annual reports. The contents, as well as the frequency of publications vary as do the needs. In general, the information is readily available and the publications can be had upon request. Typical time service notices, bulletins, announcements, and circulars are given in Appendix A.

HISTORICAL BACKGROUND OF ATOMIC TIME

Present primary time standards, as maintained by national laboratories, are based on cesium atomic oscillators which are made either in the laboratories or by a commercial firm. The time maintained by these oscillators is referred to as atomic time. Historically, it was the weighted average of nine cesium atomic standards which were located in nine laboratories in four countries.² This average was maintained by the U. S. Naval Observatory (USNO) and formulated the atomic time scale referred to as A. 1. A. 1 is presently the

average of an ensemble of 15 to 30 commercial cesium atomic standards maintained at the USNO.³ Each individual national laboratory also maintained an atomic time scale identified with a laboratory such as the U. S. Atomic Time (USAT) of the National Bureau of Standards which is now known as AT(NBS). Other examples are the Greenwich atomic time (GA) and now the GA2 of the Royal Greenwich Observatory, and the A3 of the BIH.

As the various atomic time scales went through the process of evolution it became obvious to many that an international standard must be adopted.^{4, 5} Thus, the XIIIth General Conference of Weights and Measures (CGPM) adopted in 1967, the definition of the second as "the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium atom 133." The CGPM also defined International Atomic Time (TAI) as "the time coordinate established by the BIH on the basis of the readings of atomic clocks operating in various establishments conforming to the definition of the seconds, the unit of time of the International System (SI) of Units."

The XIIth Plenary Assembly of the International Radio Consultative Committee of the International Telecommunication Union, adopted in 1970 the improved UTC system. This system eliminated the changing frequency offset between UTC and TAI and increased the step-time adjustments from 0.1 to 1 second which is now called a leap second.⁶ Thus the UTC and TAI have the same rate.

CLOCK COMPARISONS

Based on the published clock correction data of BIH, the atomic time scales, as maintained by several national laboratories and observatories, are plotted for 900 days as shown in Figures 1 and 2. In these figures the ordinate is plotted as the clock difference, Δt , in microseconds between TAI and the AT of a laboratory shown in parenthesis. The three abscissa shown are the elapsed time in days, the Modified Julian Day (MJD), and the year, month, and day (YR, MO, DY). The clock off-sets of the several laboratories were not removed, for historical reasons or by choice, so as to maintain a continuous time scale for the particular laboratory.

In Figures 1 and 2 these clock offsets were arbitrarily chosen so that the origins of the curves are near zero. The larger slope or clock rate difference between TAI and AT (NBS) shown in Figure 2 is attributed to the frequency difference between laboratory and commercial made cesium atomic standards.⁷ Although the Physikalisch-Technische Bundesanstalt (PTB) of Federal Republic of Germany and the National Research Council (NRC) of Canada also have laboratory made cesium atomic standards, it is not known if these standards

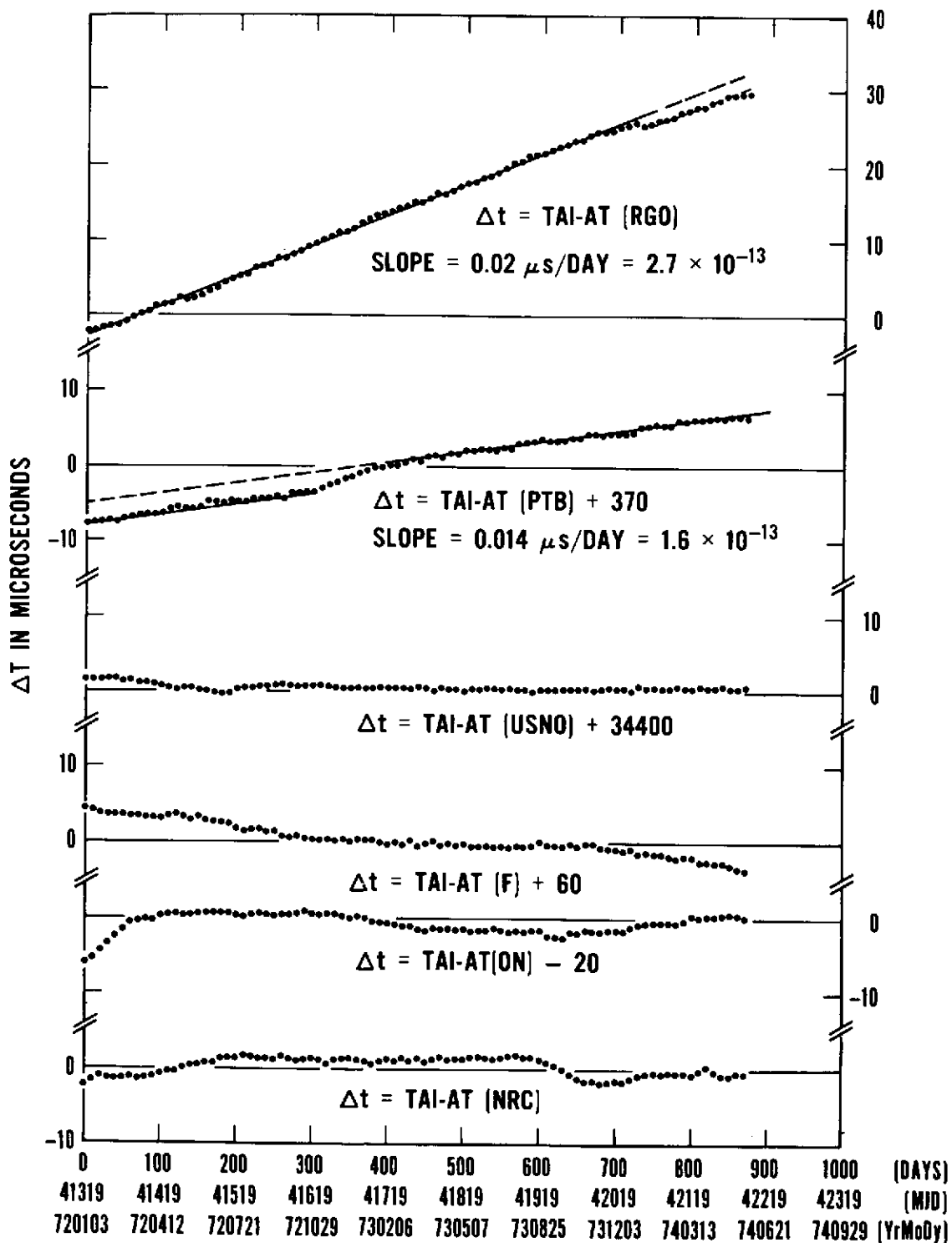


Figure 1. Independent Local Atomic Time Scales, AT (Laboratory-i), Relative to TAI (International Atomic Time). (Data Source -- Circular D Bureau International de l'Heure)

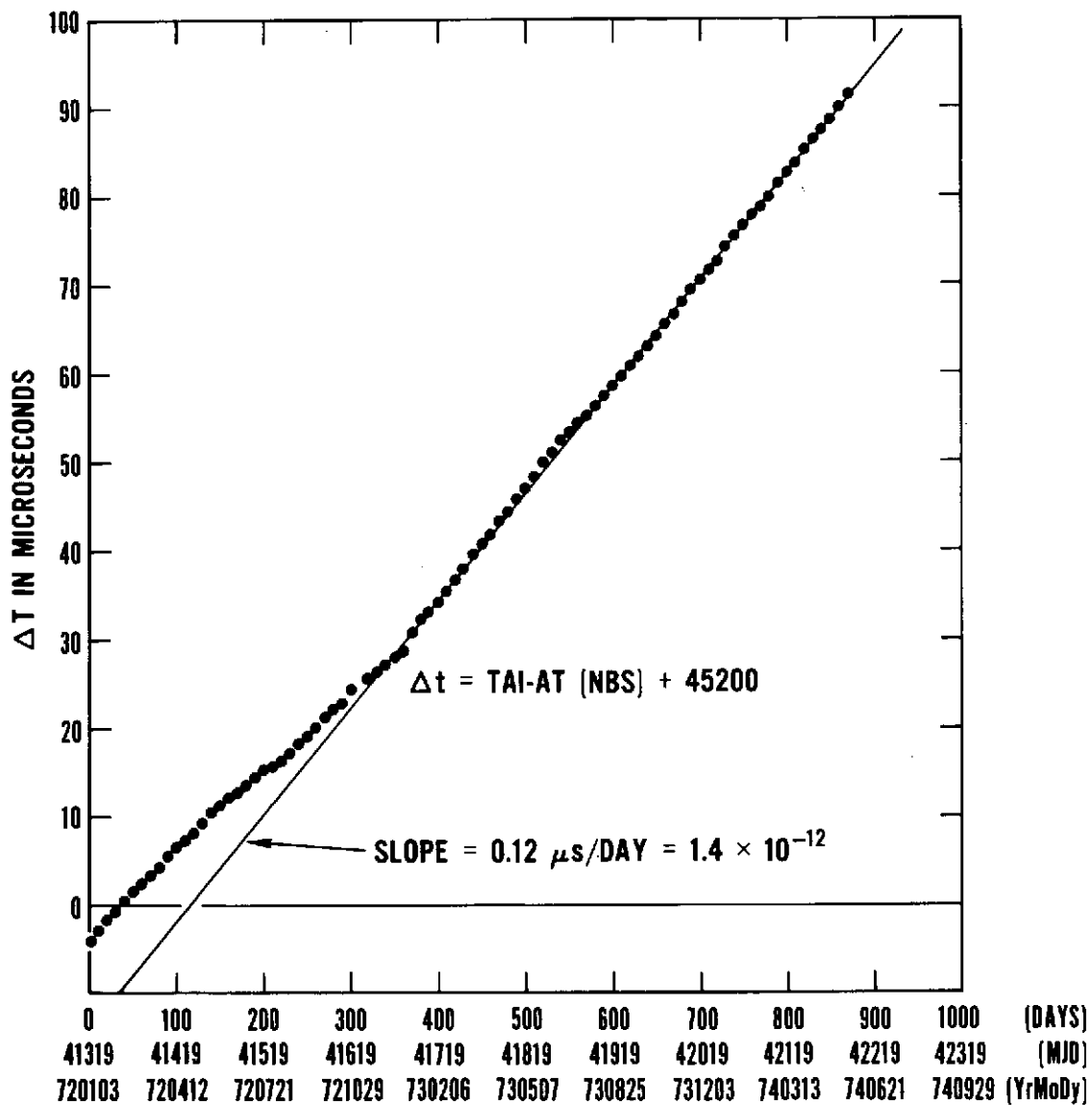


Figure 2. Independent Local Atomic Time Scale, AT (NBS),
Relative to TAI (Continued From Figure 1)

are used to steer their working standards, which are commercially made cesium atomic standards. Because the atomic time scale is maintained by a national laboratory of a country, it is the primary time scale of the country. Its relation to the International Atomic Time Scale is of interest. Only through this known relation can the time variant data collected by experimenters in different countries be correlated and compared.

Those measurements which are dependent on the earth's position are made relative to the Coordinated Universal Time (UTC). The UTC of each laboratory relative to the UTC of BIH is also plotted for 900 days as shown in Figures 3 and 4. The difference between UTC (BIH) and TAI is -10 seconds as of January 1, 1972 (with the negative sign indicating UTC late), -11 seconds on July 1, 1972, -12 seconds on January 1, 1973, -13 seconds on January 1, 1974, and -14 seconds on January 1, 1975.

Figure 5 shows the UTC time comparison of three national laboratories for 550 days using the East Coast chain of the LORAN-C navigation system as the time transfer reference signal. The East Coast chain consists of five stations with the master station being located at Cape Fear, North Carolina and four slave stations located at: Jupiter Inlet, Florida; Cape Race, Newfoundland; Nantucket, Massachusetts; and Dana, Indiana. Also shown at the bottom of the figure is the time difference between UTC (USNO) and UTC as transmitted by the Mediterranean Sea chain. Thus, these data permit the time comparison between the East Coast and the Mediterranean Sea Chains using UTC (USNO) as the time transfer reference. The obvious single break in the East Coast chain data, which occurred on MJD 41994 (Nov. 8, 1973) are due to step time corrections made at the master stations as are the two breaks in the Mediterranean Sea data which occurred on MJD 41840 (June 7, 1973) and on MJD 42090 (Feb. 12, 1974). The smaller step time corrections and frequency changes of the oscillators made from time to time at the master station will become obvious when the detailed data is examined. It should be pointed out here that the time transmitted by LORAN-C chains is required to be within only ± 25 microseconds of the master clock of the U. S. Naval Observatory (USNO-MC). This requirement (as can be seen in Figure 8) is met with a safety factor of one to three.

Figure 6 shows the relative time differences of the Mediterranean Sea chain and the Norwegian Sea chain with respect to UTC of the Istituto Elettrotecnico Nazionale (IEN) of Turin, Italy and UTC of the USNO. From this figure one can calculate the UTC time difference between IEN and the USNO and between the two LORAN-C chains as shown in Figure 7. It should be pointed out that these calculations were made on the assumption that the propagation delays are constant for the time of observation between the monitoring stations and the LORAN-C transmitters and between the slave stations and their master stations.

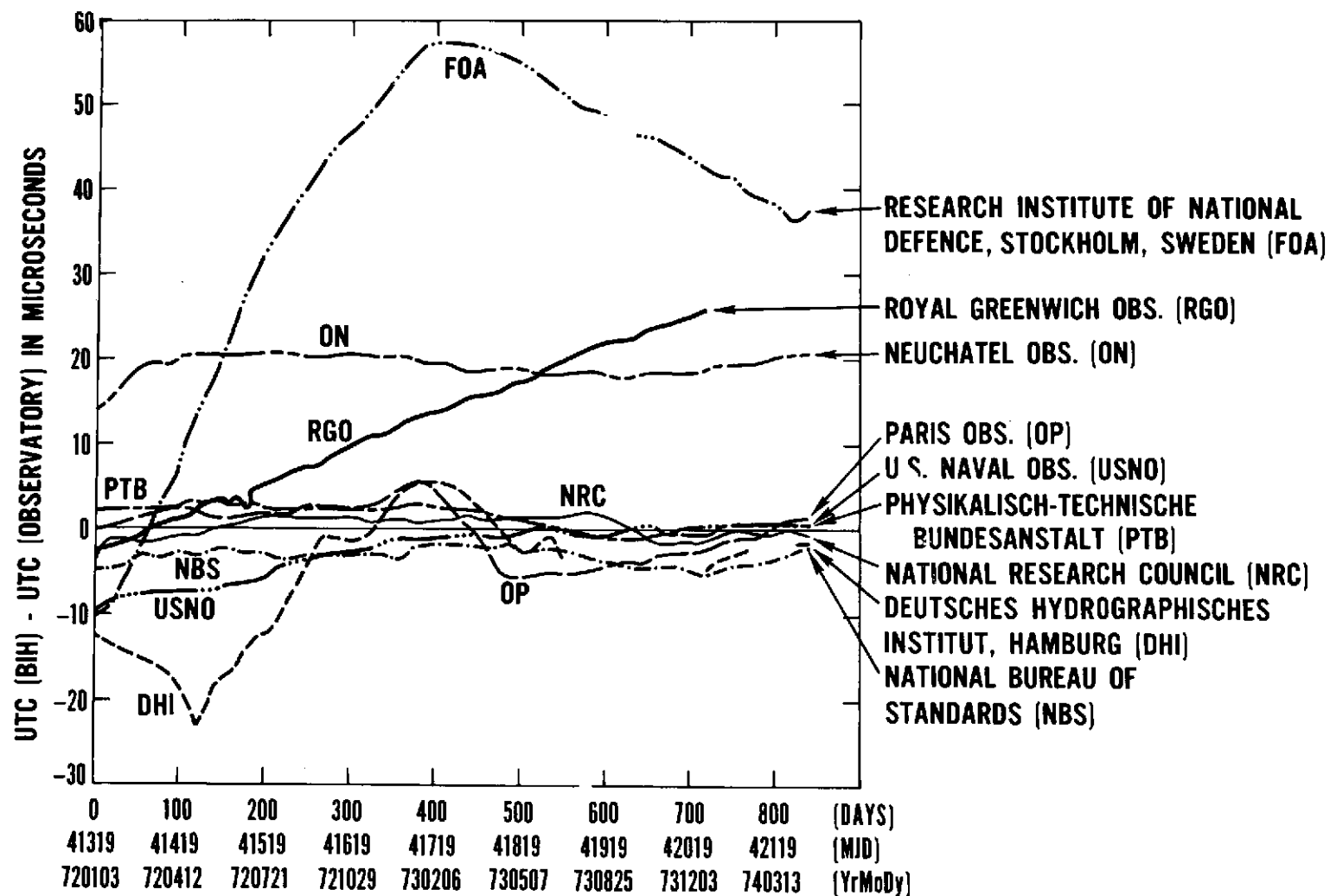


Figure 3. Coordinated Universal Time (UTC) Scales of Independent Laboratories Relative to UTC (BIH) (Data Source -- Circular D, Bureau International de l'Heure)

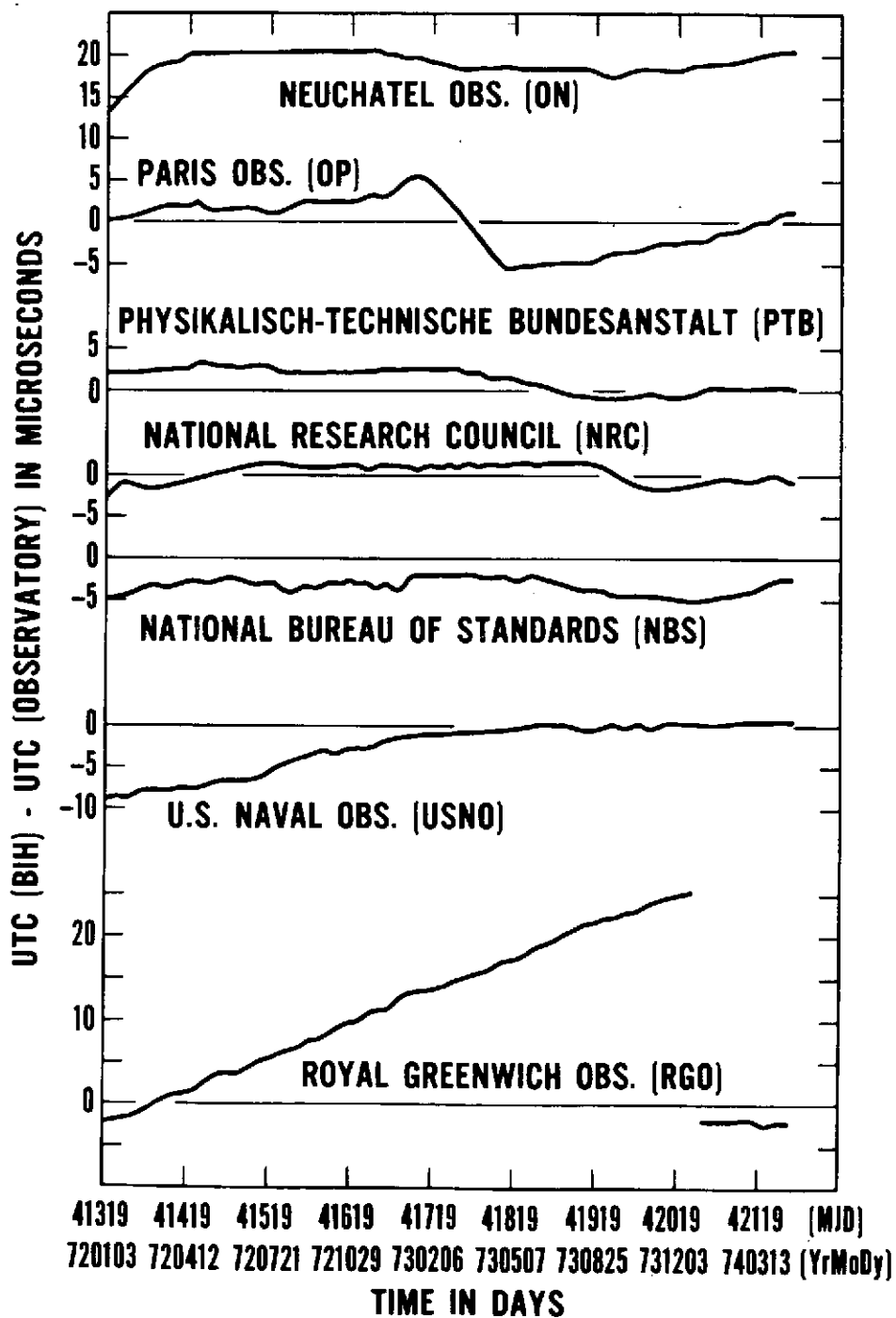


Figure 4. Coordinated Universal Time (UTC) Scale of Individual Laboratory Relative to UTC (BIH)

COMPARISON OF COORDINATED UNIVERSAL TIME (UTC) AS MAINTAINED BY NATIONAL TIME KEEPING AGENCIES
USING LORAN C EAST COAST CHAIN AS A TRANSFER REFERENCE

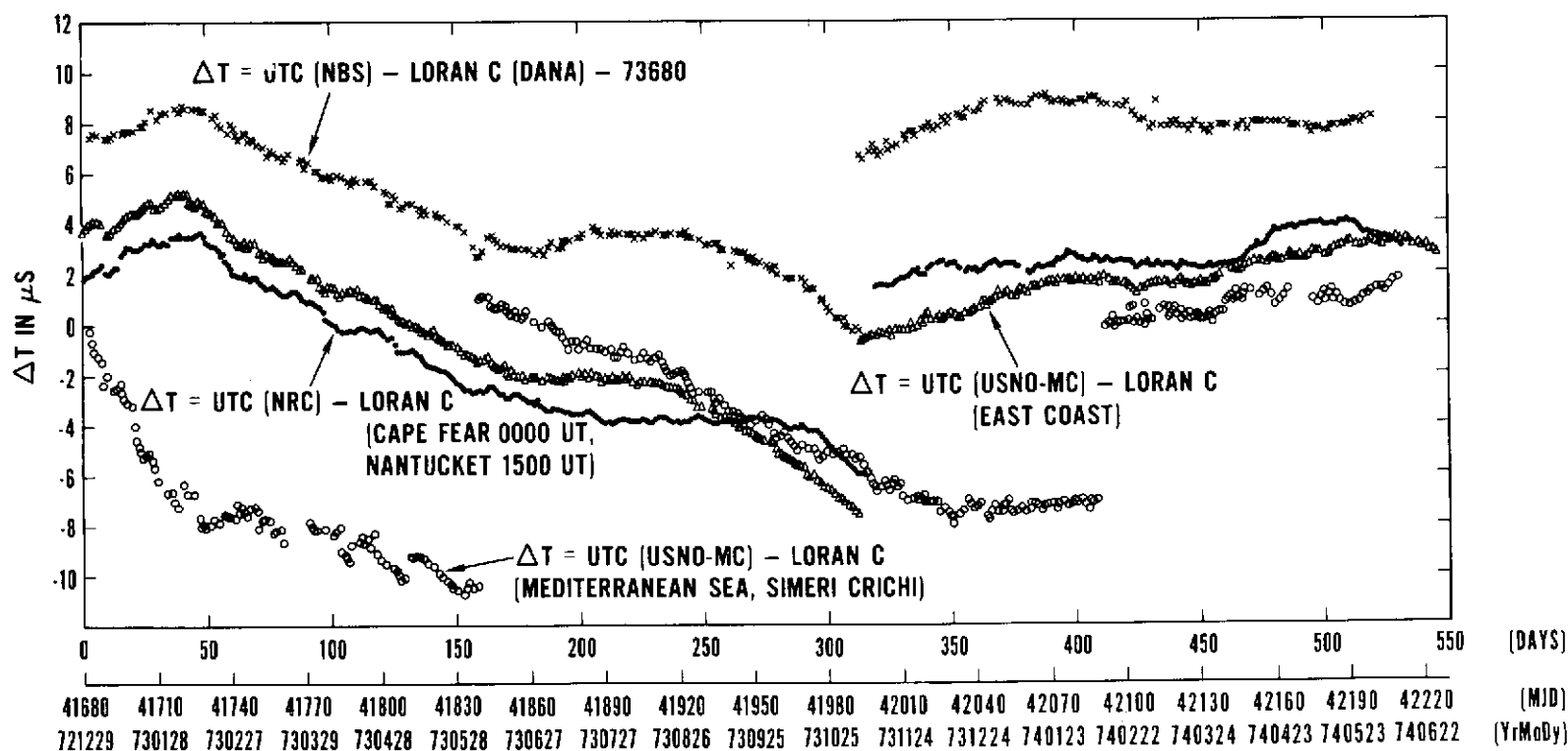


Figure 5. Comparison of Coordinated Universal Time Scales Via LORAN-C East Coast Chain
(Data Source -- National Bureau of Standards' Special Publication 236,
U. S. Naval Observatory's Daily Phase Values and Time Differences Series 4,
and Canadian National Research Council's LORAN-C Measurements)

RELATIVE TIME DIFFERENCE OF LORAN C MEDITERRANEAN SEA CHAIN (ESTARTIT) AND NORWEGIAN SEA CHAIN (SYLT)
AS MEASURED AT THE ISTITUTO ELETTROTECNICO NAZIONALE (TURIN, ITALY) AND ALSO
THE MEDITERRANEAN SEA CHAIN (SIMERI CRICHI) VS THE U.S. NAVAL OBSERVATORY

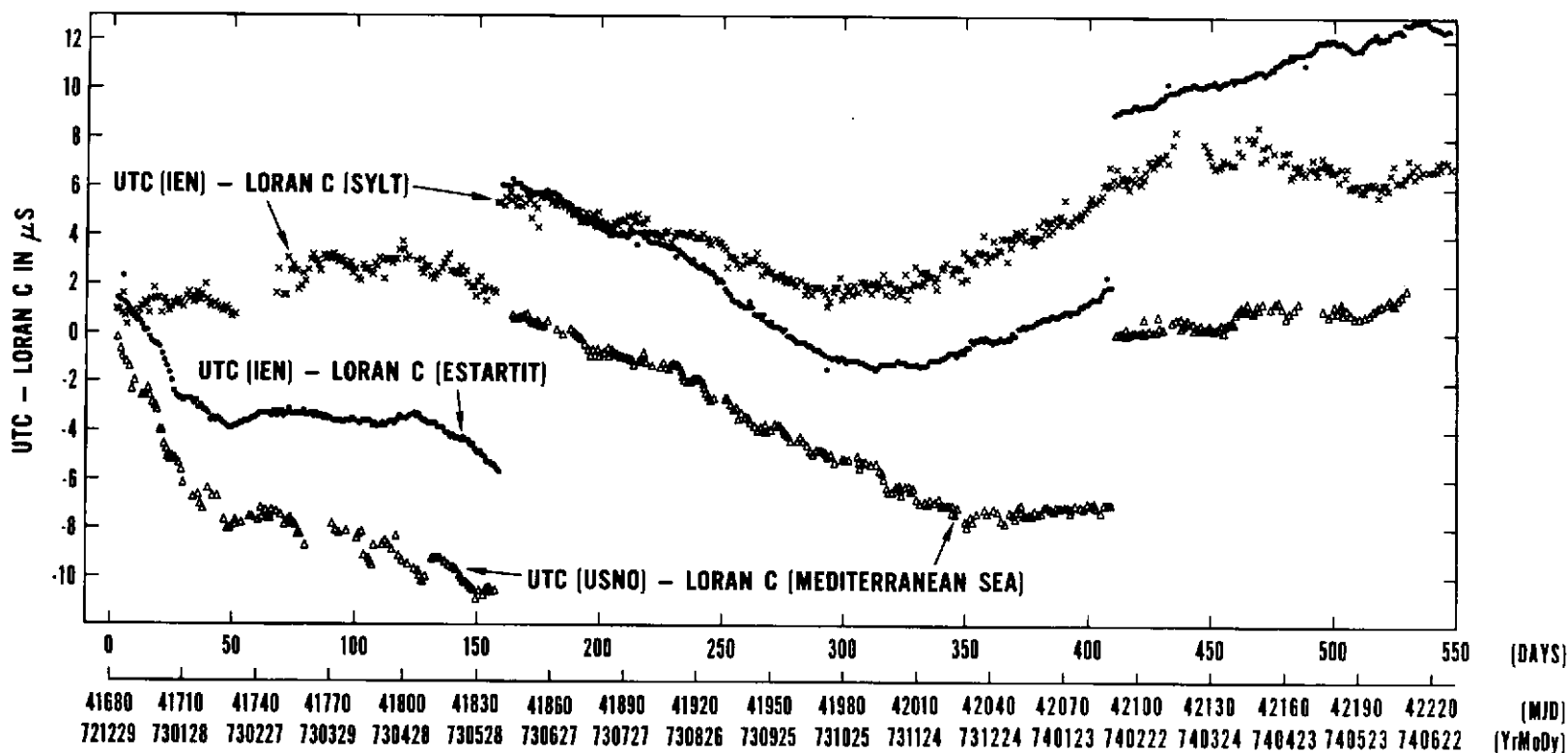


Figure 6. Comparison of Coordinated Universal Time Scales Via LORAN-C Mediterranean Sea and Norwegian Sea Chains (Data Source -- Circulars of Istituto Elettrotecnico Nazionale -- Tourin, Italy and U. S. Naval Observatory's Daily Phase Values and Time Differences Series 4)

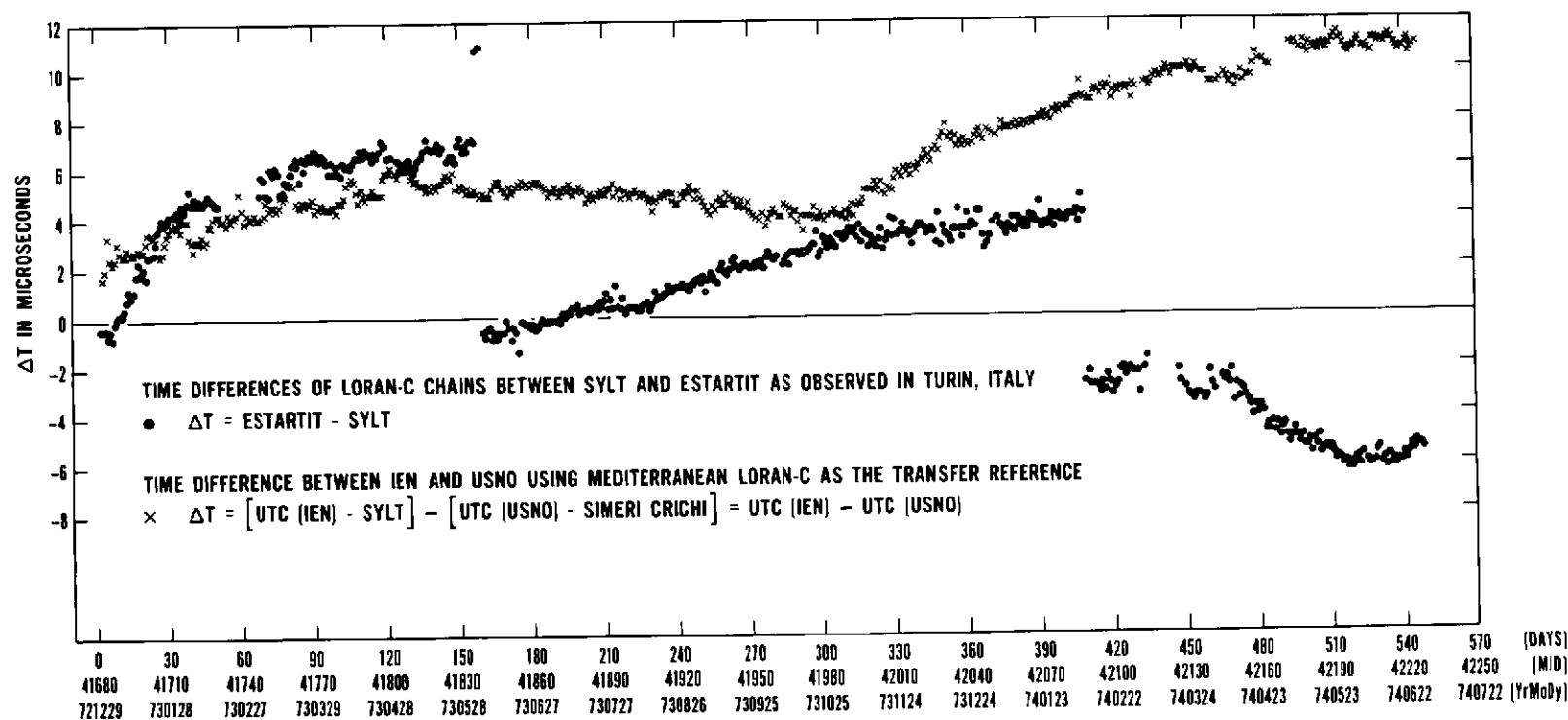


Figure 7. Comparison of Time Transmissions of LORAN-C Chains Via an Independent Monitoring Laboratory (IEN) and of Coordinated Universal Time Scales of Two Independent Laboratories Via Multiples of LORAN-C Chains

This assumption is reasonable for a short period of time (days), and is under question for a longer period of time (months or longer).

LONG-TERM TIME STABILITY OF LORAN-C CHAINS

Figure 8 shows the time differences of six of the eight LORAN-C chains relative to the master clock of the U.S. Naval Observatory (USNO-MC) as a function of time for about 900 days. Figure 9, 10, and 11 show the time difference of nine individual LORAN-chains relative to the USNO-MC. Figure 9 shows the present behavior of time controlled LORAN-C chains. Figures 10 and 11 show the progress of implementing the time control of a LORAN-C chain. In Figure 11, the performance of the West coast LORAN-D chain, which was recently implemented, is also given.

For convenience some reference information on LORAN-C and LORAN-D is given in Appendix B of this report. Table B-1 gives the stations of the nine LORAN-chains, and their repetition rates. Users of LORAN-C are advised that the repetition rate for each chain has been changed from time to time since 1970. This is done to avoid cross chain interference of the LORAN-C transmissions and to identify the chains. Table B-2 gives the basic group repetition rates. Table B-3 gives the LORAN-C group period in microseconds for basic and specific rates. Table B-4 gives the phase reversal coding sequence of the eight pulses within each group for the master and slave stations.

USE OF UTC AND LORAN-C

Based on the excellent performance of the clocks maintained by the national laboratories and observatories it is obvious that special facilities and supporting personnel are required to maintain a constant time scale in addition to an ensemble of highly accurate clocks. This is particularly true if the time scale is to be compared relative to another such as UTC (BIH) or TAI (BIH). Users who have requirements for clock time accurate to a few microseconds or better relative to a national time standard such as USNO-MC or UTC (NBS) must use the corrections provided by the national time keeping agencies. This is true even for precise time interval users who may correlate periodicities or compare independent observations which were made over a long span of time.

The weekly time corrections made to the LORAN-C transmissions are determined by real time measurements made by monitoring stations. In addition, portable clocks or satellite time transfer techniques are used to measure the clock differences between the monitoring stations and the USNO. From these clock measurements post corrections are occasionally generated to correct the weekly LORAN-C corrections. New users of precise time must pay special attention to the proper use of the circulars, bulletins, or announcements issued by the national laboratories.

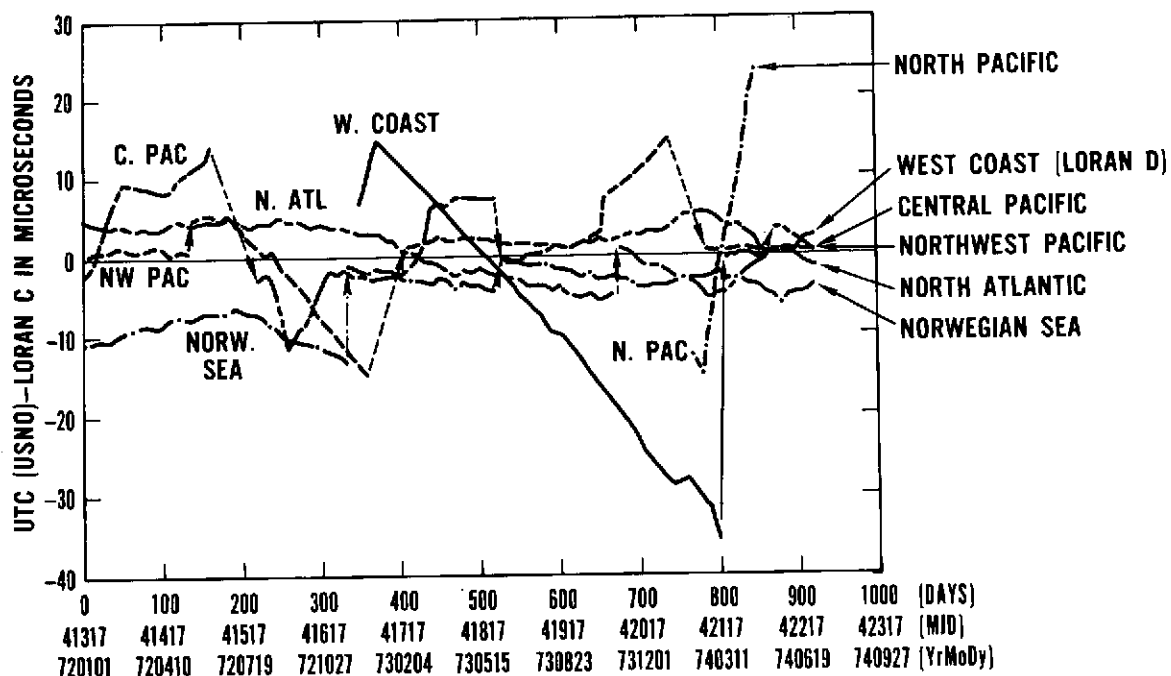


Figure 8. Performance of LORAN-C Transmissions as a Precise Time Reference Signal (Data Source -- U. S. Naval Observatory Daily Phase Values and Time Differences Series 4)

TYPICAL NASA TRACKING STATION CLOCK PERFORMANCE

NASA Spaceflight Tracking Data Network (STDN) is equipped with cesium atomic frequency standards, VLF receivers, LORAN-C receivers and WWV receivers. Each station has at least one cesium beam tube standard with automatic backup to a rubidium gas cell standard and a crystal oscillator standard⁸ in the event of a failure. Some sites have two cesium standards -- one prime and one backup. Eventually, by late 1975, all sites will have two cesium standards. Each station also has either a dual redundant or a triple redundant majority logic time code generating system. The timing systems have many and varied frequency, pulse, and time code outputs to meet station frequency and time requirements.

The station clock is rated with respect to the USNO-MC via a naval communications VLF transmission such as the VLF station NAA at Cutler, Maine. When it has been determined that the frequency of the station clock deviates by more than $\pm 1 \times 10^{-12}$, for three months or longer, the station timing engineer is directed by the network operation engineer in charge of timing to change the clock frequency by an amount to minimize the deviation. A typical performance record is shown in Figure 12 which shows the phase difference

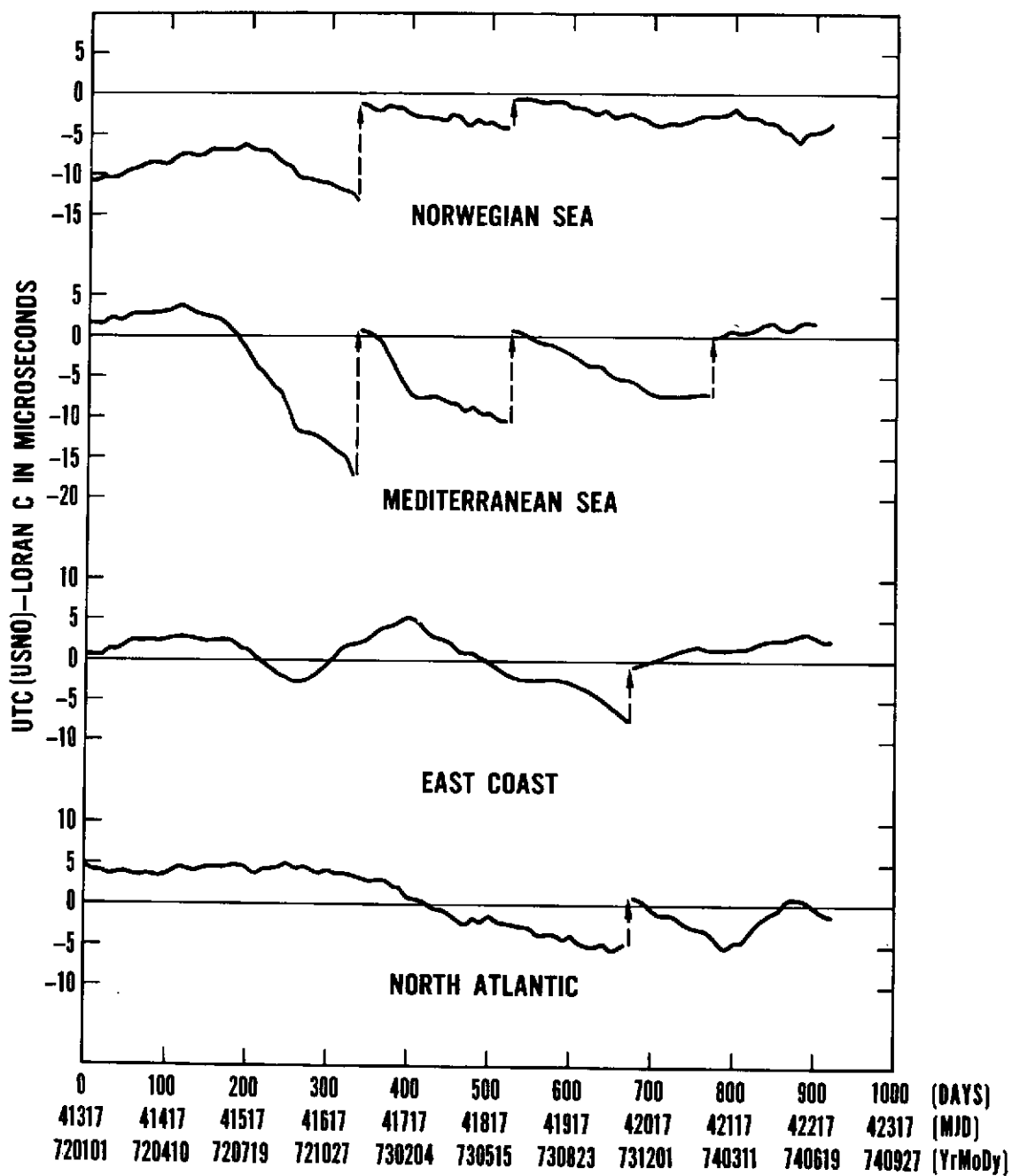


Figure 9. Performance of Individual LORAN-C Chains Relative to U. S. Naval Observatory Master Clock

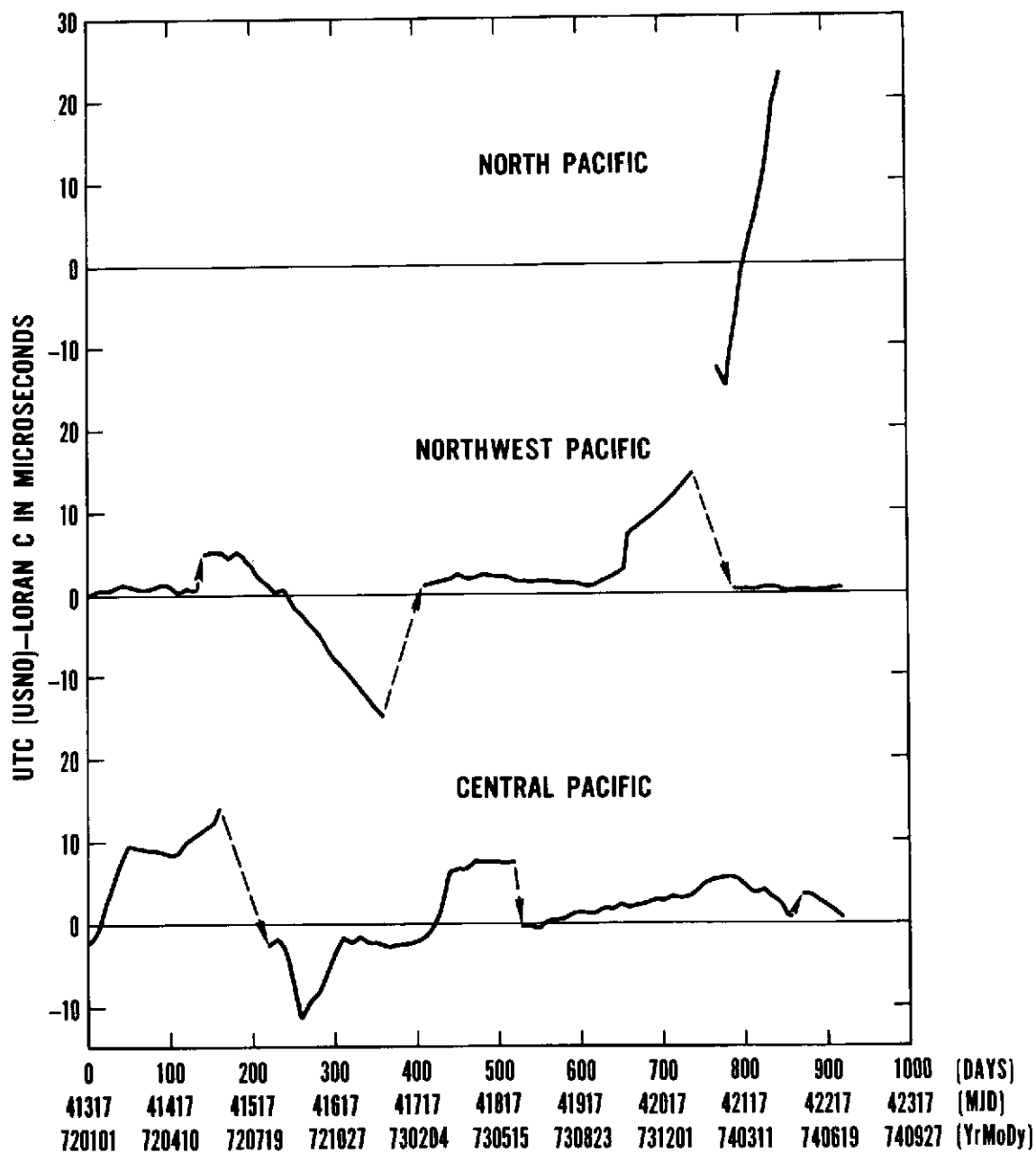


Figure 10. Performance of Individual LORAN-C Chains Relative to U.S. Naval Observatory Master Clock -- Continued From Figure 9

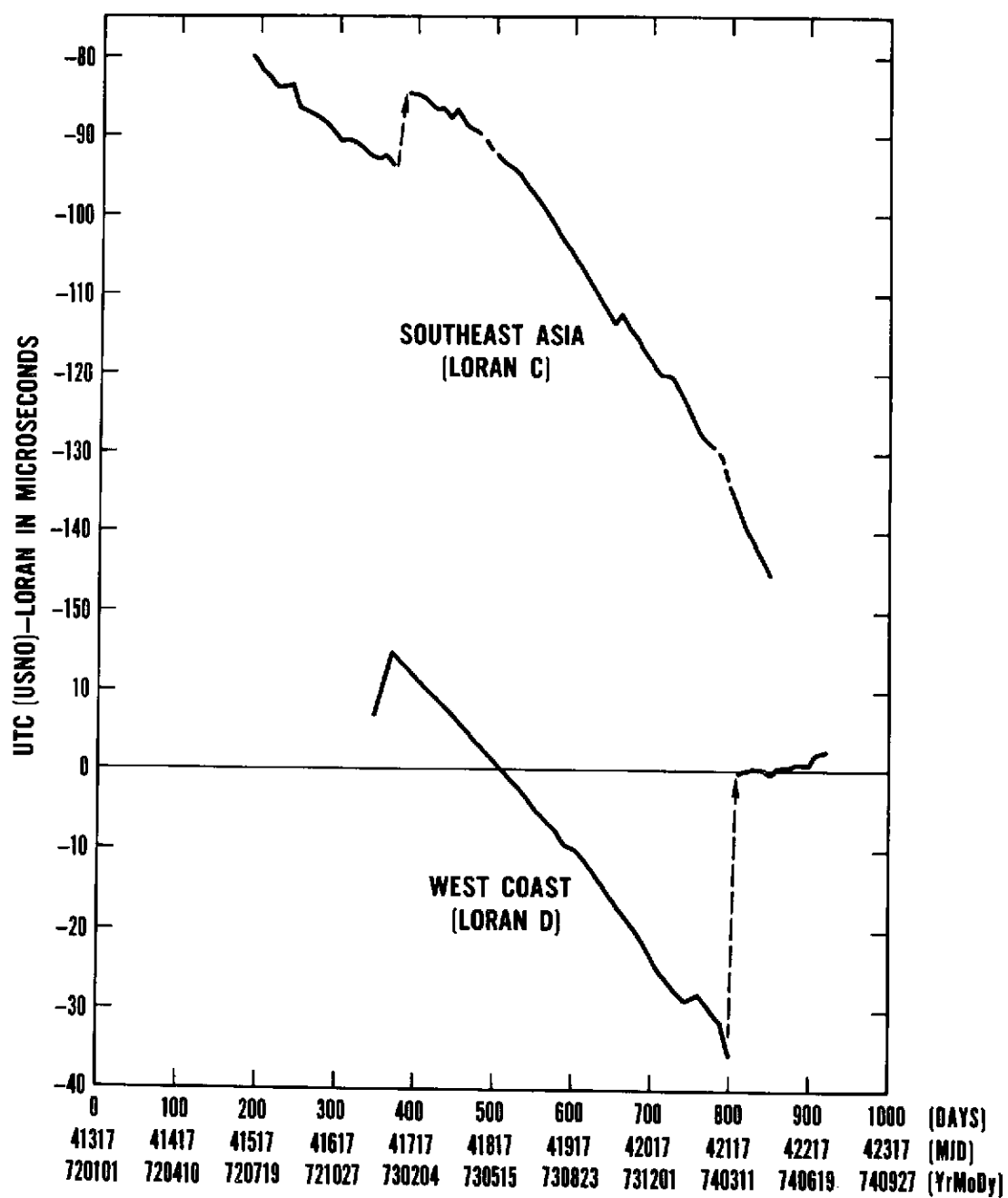


Figure 11. Performance of Individual LORAN-C Chains Relative to U.S. Naval Observatory Master Clock -- Continued From Figure 10

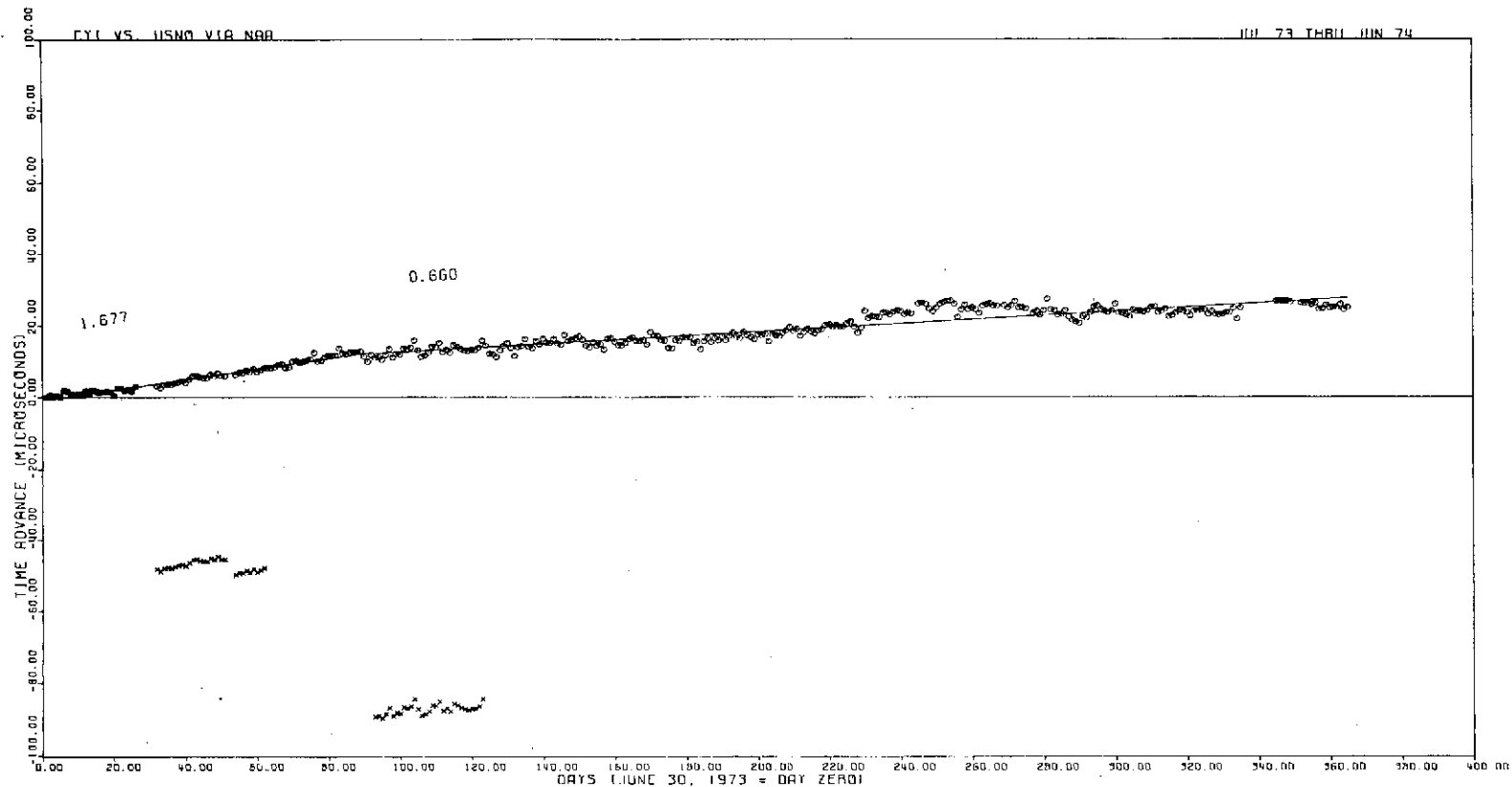


Figure 12. Frequency Comparison and Rating of NASA Tracking Station Clock at Canary Island (CYI) Relative to U. S. Naval Observatory Master Clock Via Naval Communication VLF Station NAA, Cutler, Maine

between the Canary Island station clock relative to the USNO-MC (labeled as time advance) as a function of time for fiscal year 1974. The phase difference measurement is actually made by using the NAA VLF station as the transfer frequency reference. When the VLF phase suffered a phased jump, as indicated by the crosses which are not in coincidence with the circles, the phase is corrected. If the VLF phase record is discontinuous, eg., due to propagation anomalies, the phase jump can often be measured and corrected as shown by the circles. If the discontinuity is due to equipment failure, the phase jump can only be estimated. Since a phase jump can be several cycles, the actual measured VLF phase differences often fall outside the range of the scale ± 100 microseconds. The fact that the phase of a VLF signal is not continuous is a major shortcoming for time transmissions. The use of dual VLF for time transmission is an approach to remove or to reduce the phase jumps.

The station clock is synchronized via a standard time signal emission, such as WWV, for coarse time. The fine time is obtained via a LORAN-C signal. Those stations which are within the range of the groundwave propagated signals at 100 kHz, can usually maintain their clocks to ± 20 microseconds or better depending on the operation procedure and geographical location relative to a LORAN-C chain. Figure 13 shows the Canary Island (CYI) station clock relative to USNO via Estartit, a slave station of the Mediterranean Sea chain. The cross in this figure represents the time difference and the circle, the phase difference. The least square fit of the phase difference of a segment of data is the frequency difference between the station cesium frequency standard and the USNO-MC. It is interesting to compare these frequency differences as measured via NAA (Figure 12) and LORAN-C Mediterranean Sea chain (Figure 13). The agreement is within 0.5×10^{-12} .

The best performance of a NASA station clock maintained to the USNO-MC is that of the station at Merritt Island, Florida (MIL) as shown in Figure 14. For the data shown it actually surpasses the performance of the LORAN-C East Coast chain. While the East Coast chain was used as the transfer time reference, the fact that the frequency of the station clock was not adjusted probably accounts for its superior performance.

When a NASA station is located outside the range of the groundwave propagated signal of a LORAN-C chain such as Carnarvon in northwest Australia, the skywave propagated signal was used. For convenience in calculation it was assumed that the same mode of propagation took place for the path between the station and the transmitter. Figure 15 shows the station clock performance at Carnarvon relative to USNO-MC via the 5th hop propagated from Iwo Jima of the Northwest Pacific LORAN-C chain. It can be seen from this figure that the Carnarvon station clock was maintained to within 75 microseconds of USNO-MC for the year shown.

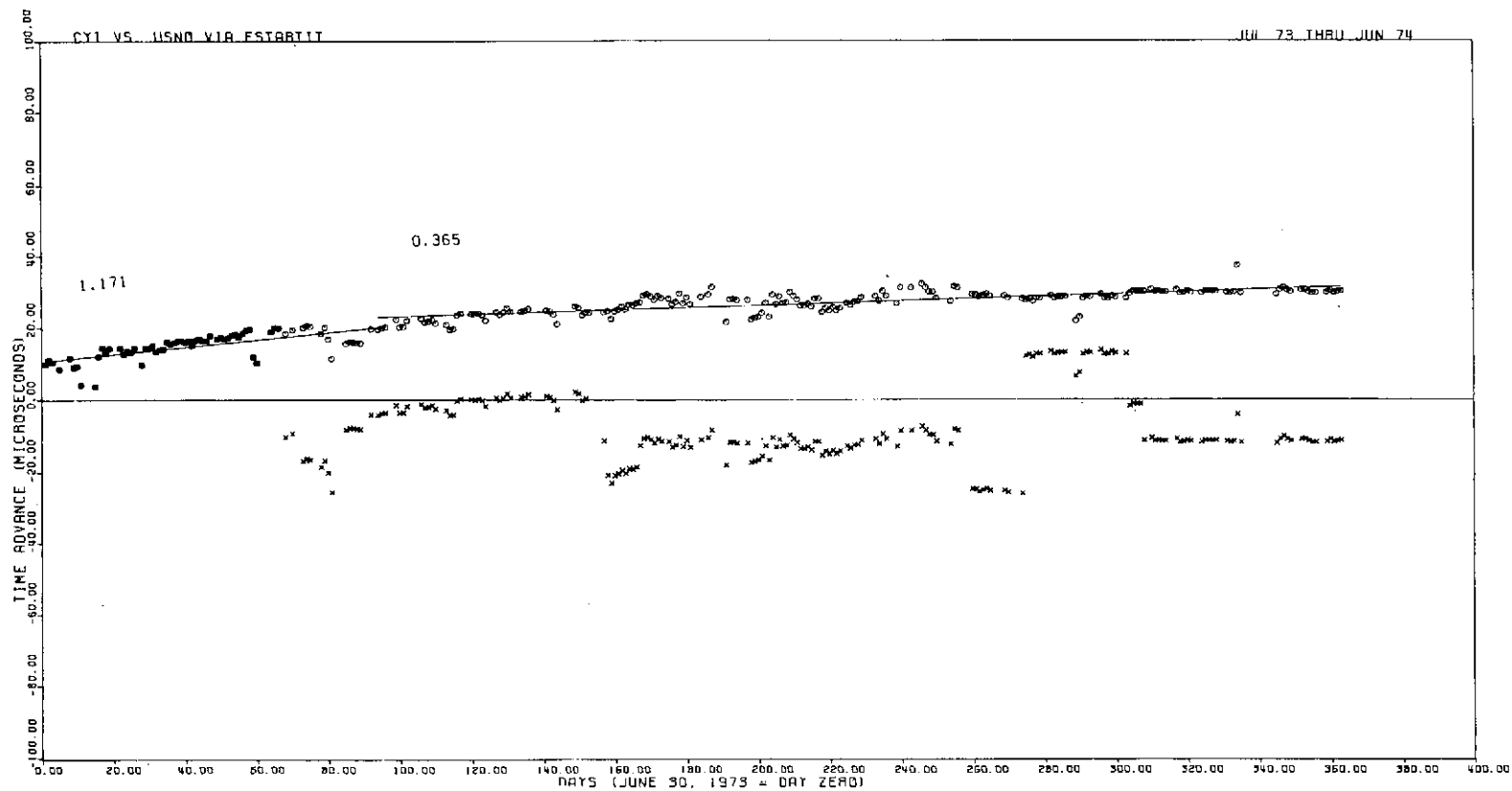


Figure 13. Time Comparison and Control of NASA Tracking Station Clock at Canary Island (CYI) Relative to U. S. Naval Observatory Master Clock Via LORAN-C Mediterranean Sea Chain

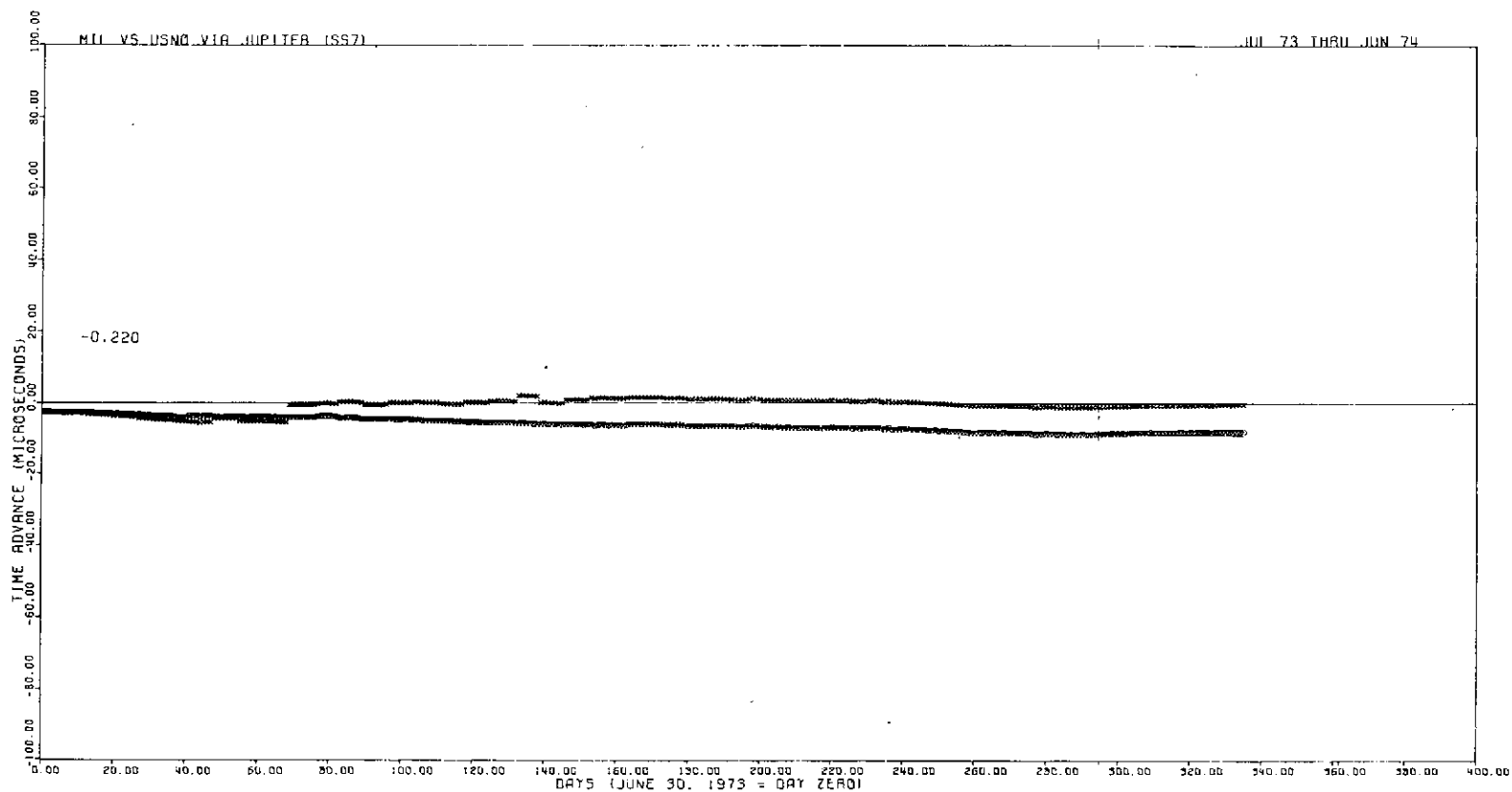


Figure 14. Performance of NASA Tracking Station Clock at Merritt Island, Florida (MIL)
Relative to U. S. Naval Observatory Master Clock Via LORAN-C East Coast Chain
(This is the Best Performance of a NASA Tracking Station Clock Among Twenty)

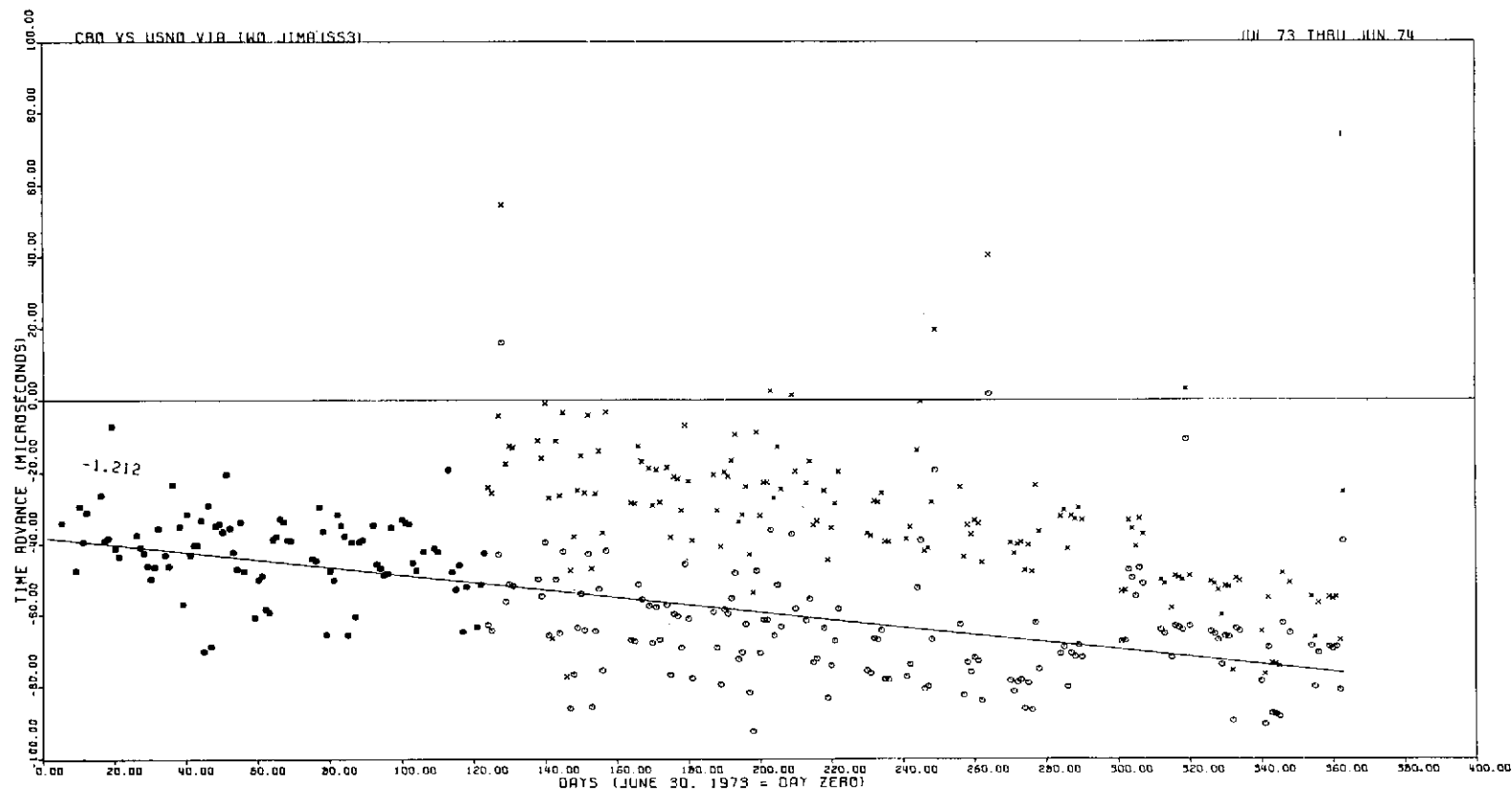


Figure 15. Time Comparison and Control of NASA Tracking Station Clock at Carnarvon, Australia (CRO) Relative to U. S. Naval Observatory Master Clock Via a Skywave Propagated Signal From LORAN-C Northwest Pacific Chain

Northwest Pacific LORAN-C chain. It can be seen from this figure that the Carnarvon station clock was maintained to within 75 microseconds of USNO-MC for the year shown.

Although extensive analysis of the performance of the NASA's station clocks cannot be presented in this paper, enough evidence has been presented to the users for the need of the corrections to frequency or time transfer reference signals if they are to be used to maintain the users' clocks. Some evidence was also presented to support the body of opinion that the best performance of a clock is achieved by fewer corrections or perturbations.

The author wishes to express his appreciation to Mr. John K. Jones, GSFC Network Operation Engineer in charge of timing for implementing the computer data reduction and analysis of the NASA station clocks relative to USNO master clock and for providing the graphs to the author for publication. He also wishes to acknowledge the assistance of Leslie Lobel who plotted Figures 1 through 11 during the summer of 1974.

REFERENCES

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7. Private communication with J. A. Barnes of NBS.
8. Cesium beam standards are Hewlett-Packard's models 5060, 5061A, and 5061A with option 004 high performance cesium beam tube. Rubidium gas cell standards are Varian Associates' Model R-20 and Tracer Model 304D. Crystal oscillators are Hewlett-Packard's Model 106 and Salzer's Model A5.

APPENDIX A

U. S. NAVAL OBSERVATORY
WASHINGTON, D.C. 20390

28 AUGUST 1974

DAILY PHASE VALUES AND TIME DIFFERENCES SERIES 4

NO. 395

REFERENCES: (A) TIME SERVICE INFORMATION LETTER OF 15 AUGUST 1973
(B) TIME SERVICE ANNOUNCEMENT, SERIES 9, NO. 36 (LORAN-C)
(C) DAILY PHASE VALUES AND TIME DIFFERENCES, SERIES 4, NO. 389 (LORAN-D)
(D) DAILY PHASE VALUES AND TIME DIFFERENCES, SERIES 4, NO. 195 (TV)

THE TABLE GIVES: UTC(USNO MC) - TRANSMITTING STATION

UNIT = ONE MICROSECOND

*MEASURED BY USNO TIME REFERENCE STATIONS WITHIN GROUND WAVE RANGE BUT CORRECTED TO REFER TO USNO MASTER CLOCK.

**COMPUTED FROM DIFFERENTIAL PHASE DATA PROVIDED BY THE U.S. COAST GUARD STATIONS OPERATING ON THE NORTH ATLANTIC REPETITION RATE AND FROM USNO MEASUREMENTS.

		LORAN-C* SS3	LORAN-C* S1	LORAN-C SS7	LORAN-C** SL3	LORAN-C** SL1	LORAN-C** SL7	
FREQUENCY KHZ (UTC)		NORTHWEST PACIFIC 100	CENTRAL PACIFIC 100	EAST COAST U.S.A. 100	NORWEGIAN SEA 100	MEDITERRANEAN SEA 100	NORTH ATLANTIC 100	
MJD								
AUG.	14	42273	-3.5	-	0.6	-3.8	1.2	-5.1
	15	42274	-3.5	-	0.5	-3.7	1.4	-5.1
	16	42275	-3.6	-	0.4	-3.8	1.1	-5.3
	17	42276	-3.5	-	0.4	-3.7	1.3	-5.4
	18	42277	-3.5	-	0.3	-3.6	1.3	-5.5
	19	42278	-3.6	-	0.3	-3.5	1.4	-5.3
	20	42279	-3.6	-	0.2	-3.9	1.2	-5.7
	21	42280	-3.6	-	0.2	-3.7	1.2	-5.6
	22	42281	-3.7	-	0.1	-3.7	1.1	-5.6
	23	42282	-3.8	-	0.0	-3.4	-	-5.4
24	42283	-3.7	-	-0.2	-3.7	-	-5.8	
25	42284	-3.7	-	-0.2	-3.8	-	-5.9	
26	42285	-3.7	-	-0.2	-3.9	-	-6.0	
27	42286	-3.8	-	-0.3	-3.6	-	-6.0	
28	42287	-3.6	-	-0.3	-3.5	-	-5.9	

FREQUENCY KHZ (UTC)		LORAN-C** SH3 SOUTHEAST ASIA 100	LORAN-C* SH7 NORTH PACIFIC 100	LORAN-D S7 WEST COAST U.S.A. 100	6 OMEGA ND 10.2 6,000+	7 OMEGA ND 13.1 6,000+	5 OMEGA ND 13.6 6,000+
MJD							
AUG. 14	42273	-162.3	-	4.4	427	428	428
15	42274	-162.4	-	4.3	428	429	429
16	42275	-162.1	-	4.4	428	429	429
17	42276	-162.5	-	-	428	430	431
18	42277	-162.9	-	-	428	430	431
19	42278	-	-	4.5	428	429	430
20	42279	-	-	4.6	-	-	-
21	42280	-	-	4.8	-	-	-
22	42281	-	-	4.7	425	426	427
23	42282	-	-	4.7	426	426	427
24	42283	-	-	-	425	426	427
25	42284	-	-	-	425	426	427
26	42285	-	-	5.0	426	427	428
27	42286	-	-	5.1	426	427	428
28	42287	-	-	5.1	425	425	428
FREQUENCY KHZ (UTC)		1 OMEGA T 13.6 11,000+	4 GBR 16.0 19,000+	2 NAA 17.8 3,000+	3 NLK 18.6 12,000+	8 NBA 24.0 11,000+	WASHINGTON, DC WTTG CHANNEL 5 EMITTED
MJD							
AUG. 22	42281	627	518	224	589	-	3.9
23	42282	627	517	223	589	-	3.9
24	42283	627	517	223	589	073	3.9
25	42284	628	517	223	588	073	-
26	42285	628	518	224	589	072	3.8
27	42286	628	516	222	589	071	3.8
28	42287	627	518	223	589	070	-

DAILY PHASE VALUES AND TIME DIFFERENCES SERIES 4, NO. 395 (CONTINUED)

		NATIONAL TELEVISION NETWORKS							
		NBC	NBC	CBS	CBS	ABC	ABC		
		19:25:00 UT	19:31:00 UT	19:26:00 UT	19:32:00 UT	19:27:00 UT	19:33:00 UT		
MJD									
AUG.	22	42281	27,271.2	20,248.6	6,831.2	33,175.2	9,238.8	2,216.3	
	23	42282	7,292.7	3,215.1	23,088.8	16,066.1	25,532.4	18,509.9	
	24	42283	10,514.9	3,492.3	29,832.3	22,792.5	26,978.6	19,820.0	
	25	42284	2,452.0	28,659.2	22,240.1	15,219.4	10,652.7	3,493.6	
	26	42285	20,856.2	1,126.1	5,131.0	-	6,154.5	-	
	27	42286	24,450.0	17,426.6	21,588.1	14,563.4	22,448.5	15,428.0	
	28	42287	11,008.6	406.2	4,277.1	30,621.0	5,375.3	31,719.5	

NOTES:

(1) PROPAGATION DISTURBANCES WERE OBSERVED NEAR THE FOLLOWING TIMES:

23 AUG. 1135/3
24 AUG. 1430/3
27 AUG. 1855/3
28 AUG. 1655/4.

(2) NAVY STATION OFF-AIR TIMES:

NBA 25 AUG. 1127 TO 1128 UT
1433 TO 1434 UT
1910 TO 1912 UT

(3) (SH3) SOUTHEAST ASIA LORAN-C

12 AUG. -161.5
13 AUG. -160.5

(4) (SL3-W) NORWEGIAN SEA LORAN-C SLAVE SYLT, GERMANY WAS OFF THE AIR 0950 TO 1047 UT 27 AUG.

- (5) (S1-X) CENTRAL PACIFIC LORAN-C SLAVE UPOLU POINT, HAWAII IS SCHEDULED TO BE OFF THE AIR 1730 TO 0430 UT DAILY COMMENCING 1730 UT 27 AUG. AND ENDING 0430 UT 1 SEP. AND FIVE-MINUTE PERIODS DAILY AT 1730, 2200, 2300, 0200, AND 0430 UT COMMENCING 1730 UT 1 SEP. AND ENDING 0435 UT 15 SEP.
- (6) (SS3-M) NORTHWEST PACIFIC LORAN-C MASTER TWO JIMA IS SCHEDULED TO BE OFF THE AIR 0130 TO 0430 UT 29 AUG.
- (7) (SS7) EAST COAST LORAN-C CHAIN IS SCHEDULED TO BE DECREASED IN FREQUENCY BY APPROXIMATELY 8.0 PARTS IN TEN TO THE THIRTEENTH AT 1600 UT 6 SEP.
- (8) (SL7) NORTH ATLANTIC LORAN-C CHAIN IS SCHEDULED TO BE DECREASED IN FREQUENCY BY APPROXIMATELY 1.0 PART IN TEN TO THE TWELFTH AT 1600 UT 6 SEP.
- (9) OMEGA STATIONS OFF-AIR TIMES:
- | | | |
|--------------|---------|-----------------------|
| NORTH DAKOTA | 24 AUG. | 0502 TO 0504 UT |
| | | 0526 TO 0535 UT |
| | | 0641 TO 0643 UT |
| | | 2217 TO 2220 UT |
| | 25 AUG. | 0435 TO 0437 UT |
| | | 0452 TO 0454 UT |
| | | 0513 TO 0515 UT |
| | | 0842 TO 0844 UT |
| | | 0921 TO 0923 UT |
| | | 0929 TO 0931 UT |
| | | 0948 TO 0950 UT |
| | | 1048 TO 1050 UT |
| | | 1257 TO 1259 UT |
| | | 1418 TO 1420 UT |
| | | 1710 TO 1712 UT |
| | | 1817 TO 1819 UT |
| | | 1918 TO 1919 UT |
| TRINIDAD | 26 AUG. | ABOUT 1005 TO 1015 UT |

BUREAU INTERNATIONAL DE L'HEURE

(B.I.H.)

61, Avenue de l'Observatoire
75014 - PARIS

Circular D84
Paris, 1973 November 5

1 - UNIVERSAL TIME AND COORDINATES OF THE POLE

Date		smoothed values				raw values			UT1-TAI s
(Oh UT) 1973	MJD	x 0 ^h 00 ^m 01 ^s	y 0 ^h 00 ^m 01 ^s	UT2-UTC 0.0001s	UT1-UTC 0.0001s	x 0 ^h 00 ^m 01 ^s	y 0 ^h 00 ^m 01 ^s	UT1-UTC 0.0001s	
Sept. 4	41 929	+ 8	+340	+ 414	+ 645	- 5	+349	+ 597	-11.9355
9	934	+ 16	+341	+ 254	+ 505	+ 6	+334	+ 521	9495
14	939	+ 25	+342	+ 94	+ 360	+ 26	+334	+ 359	9640
19	944	+ 33	+344	- 65	+ 213	+ 53	+337	+ 206	9787
24	949	+ 41	+346	- 223	+ 63	+ 35	+342	+ 86	9937
29	954	+ 48	+347	- 379	- 89	+ 59	+352	- 102	-12.0089
Oct. 4	959	+ 55	+348	- 533	- 243	+ 62	+342	- 245	0243

TAI-UTC is exactly 12s since 1973 Jan. 1st, 0h UTC.

2 - EMISSION TIME OF TIME SIGNALS, for Sept. 1973.

a - Time signals emitted in the UTC time scale, within ± 0.0002 s

CHU, DAM, DAN, DAO, DCF77, DGI, DIZ*, FFH, FTA91, FTH42, FTK77, FTN87,
GBR, HBG, IAM, IBF, JJY, LOL, MSF, NSS(hf), OMA, PPE*, RWM, (and other
signals from USSR), VNC, WWV, WWVB, WWVH, ZUO.

* DIZ : irregularities on 1973 Sept. 25.

* PPE : corrigendum : $|UTC-PPE| < 0.0002$ s since, at least, January 1973.

b - Other time signals (unit : 0.0001s) : UTC-OLB5 = + 8.

3 - COORDINATED UNIVERSAL TIME

a - From LORAN-C and Television pulses receptions

Date 1973	Sept. 4	Sept. 14	Sept. 24
MJD	41 929	41 939	41 949
Laboratory i	UTC-UTC(i)	(unit : 1 μ s)	
PTB (Braunschweig)	- 1.0	- 0.9	- 0.9
USNO (Washington) (USNO MC)	- 0.1	+ 0.1	+ 0.1
OP (Paris)	- 3.7	- 3.6	- 3.5
NBS (Boulder)	- 3.6	- 3.8	- 4.1
RGO (Herstmonceux)	+ 22.1	+ 22.3	+ 22.7
NRC (Ottawa)	+ 1.0	+ 0.6	- 0.1
FOA (Stockholm)	+ 47.9	+ 47.4	+ 46.9
ON (Neuchâtel)	+ 17.9	+ 17.8	+ 17.8
IEN (Torino)	- 4.9	- 4.5	- 4.5
NPL (Teddington)	- 30.4	- 30.7	- 30.9
QMSF (San Fernando)	+ 30.6	+ 34.1	+ 37.4
TP (Praha)	- 15.7	- 15.7	- 15.8

P. T. O.

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b - From clock transportations (unit : 1 μ s)

From "Daily Phase Values", Series 4, N° 349, USNO

National Physical Laboratory, Teddington, Middlesex, England :

1973 Sept. 17 (MJD = 41942.3), UTC(USNO MC)-UTC(NPL) = - 32.7 \pm 0.2

Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, England :

1973 Sept. 17 (MJD = 41942.6), UTC(USNO MC)-UTC(RGO) = + 19.2 \pm 0.2

Paris Observatory, Paris, France :

1973 Sept. 26 (MJD = 41951.7), UTC(USNO MC)-UTC(OP) = - 6.7 \pm 0.2

Note : A discrepancy of about 3 μ s appears between the data of the clock transportations and those obtained by LORAN-C, between America and Europe. Investigations are in progress.

4 - INDEPENDENT LOCAL ATOMIC TIME SCALES AT(i)

The value of TAI-AT(i) are given for the laboratories contributing in the formation of TAI. They are obtained from LORAN-C pulses receptions.

Date 1973	Sept. 4	Sept. 14	Sept. 24
MJD	41 929	41 939	41 949
Laboratory i	TAI-AT(i) (unit : 1 μ s)		
PTB (Braunschweig)	- 366.4	- 366.3	- 366.2
USNO (Washington) (1)	- 34 399.7	- 34 399.6	- 34 399.6
F (Paris) (2)	- 60.2	- 60.2	- 60.2
NBS (Boulder)	- 45 140.3	- 45 139.2	- 45 138.1
RGO (Herstmonceux) (3)	+ 22.1	+ 22.3	+ 22.7
NRC (Ottawa)	+ 1.0	+ 0.6	- 0.1
ON (Neuchâtel)	+ 17.9	+ 17.8	+ 17.8

(1) AT(USNO) is designated by A1(Mean) by USNO

(2) F denotes Commission Nationale de l'Heure, Paris

(3) AT(RGO) is designated by GA2 by RGO

5 - INFORMATIONS

a - Introduction of a positive leap second in UTC

A positive leap second will occur at the end of December 1973. The sequence of dates of the UTC second markers will be, as recommended by Annex I of the CCIR Report 517 :

31 Dec. 1973 , 23^h59^m59^s

31 Dec. 1973 , 23^h59^m60^s

1 Jan. 1974 , 0^h0^m0^s.

TAI-UTC will be + 13s after the introduction of the leap second.

Circular n. 26

IEN - Istituto Elettrotecnico Nazionale - Turin (Italy)

VLF, LF AND LORAN C SIGNALS RECEIVED AT IEN

REFERENCE: HP 5061 A Cesium Standard

UTC(IEN) - SIGNAL

microseconds

DATE	M.J.D.	kHz	NAA	GBR	MSF	ESTARTIT	SYLT	IAM
MARCH		UT	17.8	16.0	60.0	100.0	100.0	5,000
1974			1400	1400	1400	1400	1400	0800
			9,000+	9,000+	1,000+			$\times 10^3$
1	42107		891.0	994.5	671.5	+9.4	+7.0	-
2	8		891.0	994.0	689.0	+9.5	+7.2	-
3	9		887.0	992.5	673.0	+9.6	-	-
4	10		885.0	992.0	675.0	+9.6	+7.2	-
5	11		886.0	992.0	655.0	+9.8	+7.4	-
6	12		885.5	992.0	625.0	+10.2	+7.0	-
7	13		-	-	-	+9.9	-	-
8	14		888.0	994.0	624.5	+9.9	+7.7	-
9	15		891.0	994.0	593.0	+9.9	+8.2	-
10	16		888.0	993.5	609.0	+9.9	-	-
11	17		888.0	994.0	609.0	+10.0	-	-
12	18		887.5	995.5	592.0	+10.0	-	-
13	19		888.0	996.0	579.0	+10.1	-	1.8
14	20		889.0	996.0	579.0	+10.1	-	-
15	21		889.0	996.0	579.0	+10.1	-	1.9
16	22		890.0	995.5	581.0	+10.2	-	-
17	23		889.0	996.0	545.0	+10.2	-	-
18	24		890.0	996.0	528.0	+10.1	-	-
19	25		895.0	996.0	513.0	+10.1	-	-
20	26		893.0	996.5	482.0	+10.1	-	-
21	27		893.0	996.5	447.0	+10.1	+7.8	-
22	28		892.0	997.0	430.0	+10.2	+7.5	-
23	29		891.0	998.0	448.0	+10.2	+7.2	-
24	30		891.0	997.5	449.5	+10.2	+6.9	-
25	31		893.0	997.0	450.0	+10.3	+6.9	1.4
26	32		890.0	997.0	418.0	+10.2	+6.7	-
27	33		890.0	997.0	400.0	+10.1	+6.8	-
28	34		890.0	997.0	385.0	+10.2	+6.9	-
29	35		891.0	997.0	369.0	+10.3	+7.0	-
30	36		890.0	997.0	385.0	+10.3	+7.0	-
31	37		891.5	997.5	369.0	-	-	-

NATIONAL RESEARCH COUNCIL OF CANADA

OTTAWA, CANADA

STANDARD FREQUENCY AND TIME MEASUREMENTS

The accompanying two tables give daily values of frequency and phase for several standard frequency signals, and also corrected arrival times for signals from the East Coast Loran-C Chain.

All measurements are made with respect to time scales maintained by the Division of Physics of the National Research Council, and are based on the NRC 2.1 metre cesium beam frequency standard. All phase values and Loran-C arrival times, given in microseconds, are measured at 15:00 UT. Frequency offsets, given in parts in 10^{10} , are 24 hour averages centered at 03:00 UT.

The signals measured are as follows:

<u>Signal</u>	<u>Frequency (kHz)</u>	<u>Location</u>
¹ DO	10	Ottawa, Ontario, Canada
² CYZ40	80	Ottawa, Ontario, Canada
GBR	16	Rugby, United Kingdom
OMEGA T	12	Trinidad, West Indies
WWVB	60	Fort Collins, Colorado, U.S.A.
LORAN-C	100	Nantucket, Massachusetts, U.S.A.

¹Telephone line transmission from the Dominion Observatory HP 5060A standard which acts as a reference for all Canadian time signals broadcast from CHU transmitters.

²Experimental LF station operated by the Communications Research Centre.

NATIONAL RESEARCH COUNCIL, OTTAWA, CANADA

LORAN C MEASUREMENTS

MONTH DECEMBER 1969

DAY	UTC(NRC)-LORAN C MICROSECONDS
1	-152.9
2	-152.7
3	-152.7
4	-152.6
5	-152.7
6	*****
7	*****
8	-152.1
9	-152.3
10	-153.1
11	-153.1
12	-153.3
13	*****
14	*****
15	-153.3
16	-153.0
17	-153.3
18	-152.9
19	-152.8
20	*****
21	*****
22	-152.6
23	-152.5
24	-152.3
25	*****
26	*****
27	*****
28	*****
29	-152.2
30	-152.3
31	-152.6

THE ABOVE VALUES OF UTC(NRC)-LORAN C REFER TO EMISSION TIMES FROM THE MASTER STATION AT CAPE PEAR. THE SIGNAL MEASURED IS THAT RADIATED FROM NANTUCKET, AND ALL MEASUREMENTS ARE CORRECTED IN TERMS OF A PORTABLE CLOCK COMPARISON OF THE USNO AND NRC UTC TIME SCALES MADE ON AUGUST 7, 1969. THIS CORRECTION IS ASSUMED CONSTANT.

NATIONAL RESEARCH COUNCIL, OTTAWA, CANADA

DAILY FREQUENCY AND PHASE

DEVIATIONS

MONTH DECEMBER 1969

DAY	DO		CYZ40		GBR		OMEGA T		WWVB	
	FREQ	PHASE	FREQ	PHASE	FREQ	PHASE	FREQ	PHASE	FREQ	PHASE
1	-300.04	-7.1	-300.21	278.4	-300.18	32.1	-299.95	-0.7	0.79	-5.8
2	-299.98	-7.3	-300.12	279.5	-300.09	32.9	-300.01	-0.6	-0.62	-0.5
3	-300.02	-7.1	-300.20	281.1	-300.22	34.8	-299.83	-2.0	-0.15	0.8
4	-300.00	-7.1	-300.16	282.5	-299.21	28.0	-300.06	-1.5	0.70	-5.2
5	-300.01	-7.0	-300.05	283.0	-299.10	20.2	-299.92	-2.1	-0.45	-1.3
6	-300.01	-6.9	-299.99	282.9	-300.50	24.5	-300.10	-1.3	0.52	-5.8
7	-300.03	-6.7	-299.98	282.7	-299.93	23.9	-300.11	-0.3	-0.32	-3.1
8	-300.03	-6.5	-300.32	285.5	-300.84	31.1	-299.91	-1.1	-0.20	-1.3
9	-300.01	-6.3	-299.84	284.1	-299.69	28.5	-299.89	-2.1	0.21	-3.1
10	-299.98	-6.5	-300.32	286.8	-299.31	22.5	-299.96	-2.5	-0.32	-0.4
11	-300.04	-6.2	-299.94	286.3	-300.12	23.5	-299.91	-3.2	0.28	-2.8
12	-300.02	-6.0	-300.12	287.3	-299.77	21.5	-300.03	-2.9	-0.17	-1.4
13	-300.00	-6.0	-300.00	287.3	-300.24	23.6	-299.92	-3.6	-0.00	-1.4
14	-300.01	-5.9	*****	*****	-300.86	31.0	-299.92	-4.3	-0.10	-0.5
15	-300.03	-5.6	*****	*****	-299.41	26.0	-300.31	-1.7	0.08	-1.2
16	-299.98	-5.8	*****	289.0	-299.63	22.8	-299.78	-3.6	-0.02	-1.0
17	-300.00	-5.8	-300.01	289.1	-300.79	29.6	*****	*****	0.25	-3.2
18	-300.03	-5.5	-299.95	288.6	-300.21	31.4	*****	-3.1	-0.09	-2.4
19	-300.01	-5.4	-300.06	289.1	-299.12	23.8	-300.04	-2.8	-0.23	-0.5
20	-299.99	-5.5	-300.12	290.2	-299.70	21.2	-300.01	-2.7	0.12	-1.5
21	-300.02	-5.3	-300.10	291.1	-300.58	26.2	-300.21	-0.9	-0.21	0.3
22	-300.02	-5.2	-300.18	292.6	-299.11	18.5	-299.89	-1.9	0.08	-0.5
23	-299.95	-5.6	-300.07	293.2	-299.41	13.4	-299.89	-2.8	-0.05	-0.0
24	-300.01	-5.5	-300.06	293.8	-301.18	23.6	-300.04	-2.5	0.03	-0.3
25	-299.98	-5.7	-300.00	293.8	-300.11	24.6	-300.06	-2.0	0.17	-1.7
26	-300.06	-5.3	-299.96	293.5	-300.22	26.5	-299.65	-5.0	0.03	-2.0
27	-300.03	-5.0	-300.15	294.7	-299.42	21.5	-300.17	-3.5	-0.19	-0.4
28	-300.01	-4.9	-300.15	294.1	-300.43	25.2	-300.03	-3.2	0.02	-0.6
29	*****	*****	-300.05	296.5	-299.70	22.6	-299.92	-3.9	0.00	-0.6
30	*****	-1.3	-300.02	296.7	-300.10	23.5	-300.04	-3.6	-0.09	0.2
31	-299.99	-1.4	-300.08	297.4	-299.80	21.7	-300.04	-3.2	0.00	0.2

* FREQ = F(STATION) - F(NRC), PHASE = T(NRC) - T(STATION)

NOTE DO HP5060A STANDARD HP 1 FAILED DEC 29 AND WAS REPLACED BY HP 2 DEC 30

A-10

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NATIONAL RESEARCH COUNCIL, OTTAWA, CANADA

LORAN C MEASUREMENTS

DATE	MJD	UTC(NRC)-LORAN C MICROSECONDS
740724	42252	1.40
740725	42253	1.33
740726	42254	1.28
740727	42255	1.25
740728	42256	1.29
740729	42257	1.32
740730	42258	1.27
740731	42259	1.09
740801	42260	0.99
740802	42261	0.94

THE ABOVE VALUES OF UTC(NRC)-LORAN C REFER TO EMISSION TIMES FROM THE MASTER STATION AT CAPE FEAR AT 00:00 UT. THE SIGNAL FROM THE NANTUCKET STATION IS MEASURED AT 15:00 UT ON WEEKDAYS ONLY, AND THE ABOVE VALUES ARE ALL LINEAR INTERPOLATIONS BETWEEN ADJACENT MEASUREMENTS.

PROPAGATION AND RECEIVER DELAY CORRECTIONS ARE BASED ON A PORTABLE CLOCK COMPARISON MADE ON MAY 21, 1974. THIS CORRECTION IS ASSUMED CONSTANT.

THE TIME SCALE UTC(NRC) IS BASED ON TWICE-WEEKLY CALIBRATIONS OF AN HP CLOCK ENSEMBLE IN TERMS OF CS III, THE 2.1 METRE NRC PRIMARY CESIUM BEAM FREQUENCY STANDARD.

NATIONAL RESEARCH COUNCIL, OTTAWA, CANADA

TV LINE 10 MEASUREMENTS

DATE	MJD	UTC(NRC)-TV LINE 10 MICROSECONDS
740724	42252	32989.93
740725	42253	11848.17
740726	42254	32138.12
740727	42255	
740728	42256	
740729	42257	14176.54
740730	42258	30433.50
740731	42259	13323.79
740801	42260	29580.65
740802	42261	12470.96

THE ABOVE VALUES OF UTC(NRC)-TV LINE 10 REFER TO RECEPTION TIMES OF THE FIRST HORIZONTAL LINE 10 SYNCHRONIZING PULSE RECEIVED AFTER 19:32:00 UT, ON THE CBS NETWORK, AS RELAYED THROUGH CABLE TV. NO CORRECTIONS FOR PROPAGATION OR RECEIVER DELAY ARE MADE.

APPENDIX B

Table B-1

LORAN-C DATA SHEETS

GENERAL SPECIFICATIONS AND NOTES

The latitude, longitude, and baseline lengths listed herein were furnished by the Defense Mapping Agency, Hydrographic Center and are based upon Mercury Datum 1960 - Center of Mass (CM). Appropriate geodetic satellite shifts have been added to relate these coordinates to the center of the earth.

The following parameters were used in the computations.

a. Signal propagation: Use the velocity of light in free space as 2.997942×10^8 meters/sec. and an index of refraction of 1.000338 at the surface for standard atmosphere.

b. Phase of the groundwave: As described in NBS Circular 573.

c. Conductivity: $\Sigma = 5.0$ mhos/meter (seawater). Baseline electrical distance computations were made assuming a smooth, all seawater transmission path between stations.

d. Permittivity of the earth, esu: $\epsilon_2 = 80$ for seawater

e. Altitude in meters: $h_2 = 0$

f. Parameter associated with the vertical lapse of the permittivity of the atmosphere:

$$a = 0.75$$

g. Frequency = 100 kHz

h. Fischer Spheroid (1960):

equatorial radius (a) = 6,378,166.000 meters

polar radius (b) = 6,356,784.283 meters

flattening (f) = $(a-b)/a = 1/298.3$

Inquiries pertaining to the Loran-C system should be addressed to:

Commandant (GWAN-3)
U. S. Coast Guard
400 Seventh Street, S. W.
Washington, D. C. , 20590

NOTE 1. Monitor station and/or antenna physically relocated. Positions given on old Data Sheets no longer valid. System control established using correlated numbers.

LORAN-C Data Sheet

Table B-1a

U. S. East Coast Chain - Rate SS7 (99,300 μ sec.)

26 March 1973

Station	Coordinates	Station Function	Coding Delay & Baseline Length	Major Equipment			Radiated Peak Power	Remarks
	Latitude & Longitude			Frequency Standards	LORAN-C Equipment	Xmitting Antenna		
Carolina Beach N. C.	34-03-46.50N 77-54-47.29W	Master		Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	TIP	1.0 MW	Transmissions synchro- nized to UTC. Exercises operational control of chain. Control for W.
Jupiter, Florida	27-01-58.85N 80-06-53.59W	W Secondary	11,000 μ s 2695.51 μ s	Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	400 KW	Host nation manned. Double-rated to NORLANT chain (SL7-Z).
Cape Race, Newfoundland	46-46-31.88N 53-10-29.16W	X Secondary	28,000 μ s 8389.57 μ s	Cesium/ URQ-14	FPN-46 (Tmr) FPN-45 (Xmtr)	1350 ft Tower	2.0 MW	
Nantucket, Massachusetts	41-15-12.29N 69-58-39.10W	Y Secondary	49,000 μ s 3541.33 μ s	Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	400 KW	
Dana, Indiana	39-51-08.30N 87-29-12.75W	Z Secondary	65,000 μ s 3560.73 μ s	Cesium/ URQ-14	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	
Electronics Engi- neering Center, Wildwood, N. J.	38-56-58.59N 74-52-01.94W	T Secondary	82,000 μ s 2026.19 μ s	Cesium/ URQ-11	FPN-41, FPN-46 FPN-54 (Tmrs) FPN-42, FPN-44 (Xmtrs)	625 ft Tower	200 to 400 KW	Experimental station Not normally on air.
Bermuda U. K.	32-15-53.18N 64-52-34.27W	System Monitor		URQ-14	FPN-43 (Tmr)			Control for X & Y.
Eglin AFB. Florida	Note 1.	System Monitor		5C/5P	SPN-30 (Rcvr)			Control for Z.

LORAN-C Data Sheet

Table B-1b

North Atlantic Chain - Rate SL7 (79,300 μ sec.)

26 March 1973

Station	Coordinates	Station Function	Coding Delay & Baseline Length	Major Equipment			Radiated Peak Power	Remarks
	Latitude & Longitude			Frequency Standards	LORAN-C Equipment	Xmitting Antenna		
Angissoq, Greenland	59-59-17.19N 45-10-27.47W	Master		Cesium/ URQ-11	FPN-46 (Tmr) FPN-45 (Xmtr)	625 ft Tower	500 KW	Host nation manned. Synchronized to UTC.
Sandur, Iceland	64-54-26.07N 23-55-20.41W	W Secondary	11,000 μ s 4068.07 μ s	Cesium/ URQ-11	FPN-46 (Tmr) FPN-45 (Xmtr)	1350 ft Tower	1.5 MW	Host nation manned. Double-rated to Norwegian Sea Chain (SL3Y).
Ejde, Faroe Islands	62-17-59.64N 07-04-26.55W	X Secondary	21,000 μ s 6803.77 μ s	Cesium/ URQ-11	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	Host nation manned. Double-rated to Norwegian Sea Chain (SL3M).
Cape Race, Newfoundland	46-46-31.88N 53-10-29.16W	Z Secondary	43,000 μ s 5212.24 μ s	Cesium/ URQ-14	FPN-46 (Tmr) FPN-45 (Xmtr)	1350 ft Tower	2.0 MW	Host nation manned. Double-rated to U. S. East Coast Chain (SS7X).
Keflavik, Iceland	Note 1	System Monitor		URQ-14	SPN-30 (Rcvr)			Control for W & X. Exercises operational control of NORLANT chain.
St. Anthony, Newfoundland	Note 1	System Monitor			SPN-29 (Rcvr)			Host nation manned. Control for Z.

LORAN-C Data Sheet

Table B-1c

Norwegian Sea Chain - Rate SL3 (79,700 μ sec.)

26 March 1973

Station	Coordinates	Station Function	Coding Delay & Baseline Length	Major Equipment			Radiated Peak Power	Remarks
	Latitude & Longitude			Frequency Standards	LORAN-C Equipment	Xmitting Antenna		
Ejde, Faroe Islands	62-17-59.64N 07-04-26.55W	Master		Cesium/ URQ-11	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	Host nation manned. Transmissions synchronized to UTC. Double-rated to NORLANT.
Bo, Norway	68-38-06.55N 14-27-48.46E	X Secondary	11,000 μ s 4048.16 μ s	Cesium/ URQ-14	FPN-38 & FPN-54 (Tmrs) FPN-39 (Xmtr)	625 ft Tower	250 KW	Host nation manned.
Sylt, Germany	54-48-29.24N 08-17-36.82E	W Secondary	26,000 μ s 4065.69 μ s	Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	400 KW	
Sandur, Iceland	64-54-26.07N 23-55-20.41W	Y Secondary	46,000 μ s 2944.47 μ s	Cesium/ URQ-11	FPN-46 (Tmr) FPN-45 (Xmtr)	1350 ft Tower	1.5 MW	Host nation manned. Double-rated to NORLANT (SL7W).
Jan Mayen, Norway	70-54-51.63N 08-43-56.57W	Z Secondary	60,000 μ s 3216.20 μ s	Cesium/ URQ-14	FPN-38 & FPN-54 (Tmrs) FPN-39 (Xmtr)	625 ft Tower	250 KW	Host nation manned. Control for X.
Shetland Is., U. K.	(1) 60-26-25.27N 01-18-05.22W (2) 60-26-17.49N 01-18-19.08W	System Monitor		URQ-14	FPN-46 (Tmr)			Exercises operational control of chain. Control for W, Y, Z.
	(1) North antenna (2) South antenna							

LORAN-C Data Sheet

Table B-1d

Mediterranean Sea Chain - Rate SL1 (79,900 μ sec)

26 March 1973

Station	Coordinates	Station Function	Coding Delay & Baseline Length	Major Equipment			Radiated Peak Power	Remarks
	Latitude & Longitude			Frequency Standards	LORAN-C Equipment	Xmitting Antenna		
Simeri Crichi, Italy	38-52-20.23N 16-43-06.39E	Master		Cesium/ URQ-14	FPN-38 & FPN-54 (Tmrs) FPN-39 (Xmtr)	625 ft Tower	250 KW	Temporarily synchronized to UTC.
Lampedusa, Italy	35-31-20.80N 12-31-29.96E	X Secondary	11,000 μ s 1755.98 μ s	Cesium/ URQ-14	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	ATLS Station.
Targabarun, Turkey	40-58-20.22N 27-52-01.07E	Y Secondary	29,000 μ s 3273.23 μ s	Cesium/ URQ-14	FPN-38 & FPN-54 (Tmrs) FPN-39 (Xmtr)	625 ft Tower	250 KW	
Estartit, Spain	42-03-36.15N 03-12-15.46E	Z Secondary	47,000 μ s 3999.76 μ s	Cesium/ URQ-14	FPN-38 & FPN-54 (Tmrs) FPN-39 (Xmtr)	652 ft Tower	250 KW	
Rhodes, Greece	36-25-20.66N 28-09-31.92E	System Monitor		URQ-14	SPN-30 (Rcvr)			Control for X & Y.
Sardinia, Italy	39-10-51.26N 09-09-35.02E	System Monitor			SPN-29 (Rcvr)			Control for Z.

LORAN-C Data Sheet

Table B-1e

North Pacific Chain - Rate SH7 (59,300 μ sec.)

26 March 1973

Station	Coordinates	Station Function	Coding Delay & Baseline Length	Major Equipment			Radiated Peak Power	Remarks
	Latitude & Longitude			Frequency Standards	LORAN-C Equipment	Xmitting Antenna		
St. Paul, Pribiloff Is., Alaska	57-09-12.10N 170-15-07.44W	Master		Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	400 KW	Controls X, Y, Z.
Attu, Alaska	52-49-44.40N 173-10-49.40E	X Secondary	11,000 μ s 3875.17 μ s	Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	400 KW	
Port Clarence, Alaska	65-14-40.35N 166-53-12.95W	Y Secondary	28,000 μ s 3068.97 μ s	Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	1350 ft Tower	1.8 MW	
Sitkinak, Alaska	56-32-19.71N 154-07-46.32W	Z Secondary	42,000 μ s 3284.83 μ s	Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	400 KW	

LORAN-C Data Sheet

Table B-1f

Northwest Pacific Chain - Rate SS3 (99,700 μ sec.)

26 March 1973

Station	Coordinates	Station Function	Coding Delay & Baseline Length	Major Equipment			Radiated Peak Power	Remarks
	Latitude & Longitude			Frequency Standards	LORAN-C Equipment	Xmitting Antenna		
Iwo Jima, Bonin Is.	24-48-04.22N 141-19-29.44E	Master		Cesium/ URQ-11	FPN-46 (Tmr) FPN-45 (Xmtr)	1350 ft Tower	3.0 MW	Transmissions synchro- nized to UTC.
Marcus Is.	24-17-07.79N 153-58-53.72E	W Secondary	11,000 μ s 4284.11 μ s	Cesium/ URQ-11	FPN-46 (Tmr) FPN-45 (Xmtr)	1350 ft Tower	3.0 MW	
Hokkaido, Japan	42-44-37.08N 143-43-10.50E	X Secondary	30,000 μ s 6685.12 μ s	Cesium/ URQ-11	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	
Gesashi, Okinawa, Japan	26-36-24.79N 128-08-55.99E	Y Secondary	55,000 μ s 4463.24 μ s	Cesium/ URQ-11	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	
Yap, Caroline Is.	09-32-45.84N 138-09-55.05E	Z Secondary	75,000 μ s 5746.79 μ s	Cesium/ URQ-14	FPN-46 (Tmr) FPN-45 (Xmtr)	1000 ft Tower	3.0 MW	
Saipan, Mariana Is.	15-07-47.07N 145-41-37.62E	System Monitor			SPN-30 (Rcvr)			Controls W & Z.
Fuchu, Japan	Note 1	System Monitor		Cesium	SPN-30 (Rcvr)			Controls X & Y. Time Service Monitor.

LORAN-C Data Sheet

Table B-1g

Central Pacific Chain - Rate S1 (49,900 μ sec.)

26 March 1973

Station	Coordinates	Station Function	Coding Delay & Baseline Length	Major Equipment			Radiated Peak Power	Remarks
	Latitude & Longitude			Frequency Standards	LORAN-C Equipment	Xmitting Antenna		
Johnston Is.	16-44-43.85N 169-30-31.63W	Master		Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	300 KW	Transmissions synchro- nized to UTC.
Upolo Pt. Hawaii	20-14-50.24N 155-53-08.78W	X Secondary	11,000 μ s 4972.38 μ s	Cesium/ URQ-14	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	300 KW	
Kure, Midway Is.	28-23-41.11N 178-17-29.83W	Y Secondary	29,000 μ s 5253.08 μ s	Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	300 KW	
French Frigate Shoals	23-52-05.23N 166-17-19.60W	System Monitor		5C/5P	SPN-29 (Rcvr)			Controls X & Y.

LORAN-C Data Sheet

Table B-1h

Southeast Asia Chain - Rate SH3 (59700 μ sec.)

26 March 1973

Station	Coordinates	Station Function	Coding Delay & Baseline Length	Major Equipment			Radiated Peak Power	Remarks
	Latitude & Longitude			Frequency Standards	LORAN-C Equipment	Xmitting Antenna		
Sattahip, Thailand	12-37-06.91N 100-57-36.58E	Master		Cesium/ Rubidium	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	
Campang, Thailand	18-19-34.19N 99-22-44.31E	X Secondary	11,000 μ s 2183.11 μ s	Cesium/ Rubidium	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	
Con Son, RVN	08-43-20.18N 106-37-57.39E	Y Secondary	27,000 μ s 2522.07 μ s	Cesium/ Rubidium	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	
Tan My, RVN	16-32-43.13N 107-38-35.39E	Z Secondary	41,000 μ s 2807.28 μ s	Cesium/ URQ-14	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	ATLS Station.
Udorn, Thailand	17-22-44.20N 102-47-12.40E	System Monitor		URQ-14	FPN-46 (Tmr)			Controls X, Y, Z.

U. S. Naval Observatory
Washington, D. C. 20390

Table B-1i

Daily Phase Values Series 4

17 October 1973

LORAN-D Transmissions

No. 350

Experimental transmissions of precise time are available in the western part of the United States via the LORAN-D system. These transmissions are compatible with LORAN-C timing receivers. TOC tables and computed propagation time delays between user monitoring stations and any of the transmitting stations can be obtained from USNO.

The chain operates with a repetition rate of 49,300 microseconds. Coordinates and total emission delays are:

Glendale, Nevada (M)	36° 41' 17".6 N,	114° 38' 39".3 W	ON TOC
Palmdale, California (SA)	34° 32' 40".5 N,	117° 51' 17".2 W	12,255.0 Microsec.
Middlegate, Nevada (SB)	39° 17' 08".2 N,	118° 00' 53".9 W	24,380.0 Microsec.
Little Mountain, Utah (SC)	41° 14' 46".9 N,	112° 13' 25".4 W	36,830.0 Microsec.

Effective 23 Oct. 1973 the transmission schedule of the master station (M) will be 1800 to 0200 UT seven days a week and of the slave stations (SA, SB, SC) will be 2000 to 2400 UT seven days a week. Any changes in transmission schedule will be announced in Series 4.

Continued

U. S. Naval Observatory
Washington, D. C. 20390

Table B-1i (Continued)

17 July 1974

Daily Phase Values and Time Differences Series 4

No. 389

The coordinates and total emission delays of the west coast U. S. A. LORAN-D stations are as follows:

Master Lake Meade Aux, Nellis AFB, Nv	36 ⁰ 14' 57" 296N	114 ⁰ 58' 57" 459W	ON TOC
A Slave Pearblossom, Ca	34 ⁰ 32' 40" 453N	117 ⁰ 51' 17" 220W	12,077.30 μ s
B Slave Fallon, Nv	39 ⁰ 31' 00" 402N	118 ⁰ 54' 48" 054W	24,675.14 μ s
C Slave Little Mountain, Ut	41 ⁰ 14' 46" 924N	112 ⁰ 13' 25" 413W	37,019.61 μ s
Monitor China Lake NWC, Ca	35 ⁰ 41' 14" 393N	117 ⁰ 45' 16" 168W	

The chain is maintained on time to the UTC time scale every day between the hours of 1900 and 2300 UT.

For more details see time service announcement Series 9, No. 86, of 19 Jul. 1974.

Table B-2

LORAN-C Basic Group Repetition Rates and Periods

Basic Designator	Rate (pps)	Corresponding Period for Specific Rate 0 (μsec)
SS	10	100,000
SL	12-1/2	80,000
SH	16-2/3	60,000
S	20	50,000
L	25	40,000
H	33-1/3	30,000

Table B-3

LORAN-C Group Repetition Periods for Specific Rates

Specific Rate	Basic Repetition Rate (μsec)					
	SS	SL	SH	S	L	H
0	100,000	80,000	60,000	50,000	40,000	30,000
1	99,900	79,900	59,900	49,900	39,900	29,900
2	99,800	79,800	59,800	49,800	39,800	29,800
3	99,700	79,700	59,700	49,700	39,700	29,700
4	99,600	79,600	59,600	49,600	39,600	29,600
5	99,500	79,500	59,500	49,500	39,500	29,500
6	99,400	79,400	59,400	49,400	39,400	29,400
7	99,300	79,300	59,300	49,300	39,300	29,300

Table B-4

LORAN-C Pulse Coding for Master and Slave Stations

Code Group	Pulse Phase in Degrees							
	1	2	3	4	5	6	7	8
M-1	0	0	180	180	0	180	0	180
M-2	0	180	180	0	0	0	0	0
S-1	0	0	0	0	0	180	180	0
S-2	0	180	0	180	0	0	180	180